



PHD

The GEVOteach evolution and genetics teaching project: An investigation into the place of knowledge about genetics in accepting the theory of evolution in secondary school

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The GEVOteach evolution and genetics teaching project:
An investigation into the place of knowledge about genetics in accepting the
theory of evolution in secondary school

Rebecca Mead

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Biology and Biochemistry

February 2016

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Acknowledgments

Collaborator contribution

Unless otherwise stated, this thesis is my own work. I processed and analysed all of the data and interpreted the results, with the help of my supervisor, Laurence D Hurst.

The teacher survey (Chapter 8) is a joint research venture with Loredana Buchan, a PhD student at the University of Bath who is researching how best to teach evolution in primary schools. Questions for the survey were developed collaboratively but the survey layout was designed and input to ‘SurveyMonkey’ (www.surveymonkey.net) by myself. Within this thesis, only data from secondary science teachers and secondary science pre service teachers are included. All analyses and interpretations are my own, with support from Laurence D Hurst.

Research instruments used within this study have been developed or taken inspiration from previous work. These are detailed and referenced within the relevant sections of this thesis. Permissions have been granted from the publishers of the main research papers upon which the research instruments devised here are based. These permissions are to reuse aspects of the works of Rutledge and Warden (1999), Lewis and Wood-Robinson (2000), Anderson *et al.* (2002) and Lovely and Kondrick (2008) within research questionnaires in paper and electronic forms, and for inclusion within this thesis.

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Abstract

What is the best way to teach evolution? Despite its importance, evolution is widely recognised as one of the most misunderstood topics in biology. Its eminent position within science is not fully recognised in schools and there are concerns over its unsatisfactory teaching. Many students have difficulty in accepting evidence for the theory of evolution and debate is currently in progress about how best to teach evolution in secondary schools. The GEVOteach project aims to investigate how and why acceptance of evolution may alter for school students during their education and, in particular, how knowledge of genetics may contribute to understanding and acceptance of evolution. Prior research suggests a relationship between evolution and genetics exists. In the UK, these are typically taught to 14 to 16 year old school students as separate topics with few links. Here, we report the results of a randomised trial into teaching order of these topics. A questionnaire to ascertain students' acceptance of evolution and understanding of evolution and genetics has been developed and data have been collected from over 1850 students. We report that teaching genetics first has a marked and significant impact on both evolution and genetics knowledge. This suggests a simple intervention; teaching genetics first, will improve results. However, we find only weak or moderate correlations between knowledge and acceptance. Reasons for this apparent dislocation are unclear. Qualitative data collected from focus groups suggests that not what is taught, but who evolution is taught by, is more important for acceptance. Academic ability is shown to be important in student acceptance of evolution and understanding of genetics and evolution. Teaching has a positive effect on acceptance and knowledge, but not for all students.

Abbreviations

A Level – Advanced Level

A General Certificate of Education Advanced Level qualification completed in the UK over two years and typically studied between the ages of 16 and 18. The term A Level is sometimes used to refer specifically to the second or A2 year of the course.

AS Level – Advanced Subsidiary Level

The first year of the A Level qualification, typically studied between the ages of 16 and 17. It is also a qualification within its own right.

ASE – Association for Science Education

A professional body for those involved in science education in the UK.

CINS – Conceptual Inventory of Natural Selection

An instrument designed by Anderson et al. (2002) to assess undergraduate students' understanding of natural selection.

GCSE – General Certificate of Secondary Education

A UK qualification generally taken in a number of subjects over two years and typically studied between the ages of 14 and 16.

iGCSE – International General Certificate of Secondary Education

An international equivalent of the UK GCSE qualification. It is typically more examination-based than GCSEs and is viewed by some to be more rigorous. Its use in UK schools is predominantly in independent schools.

INSET – IN-Service Training day

Staff training days within UK schools.

MATE – Measure of Acceptance of the Theory of Evolution

An instrument designed by Rutledge and Warden (1999) to assess evolution acceptance.

PGCE – Postgraduate Certificate in Education

A one year, higher education course in the UK which provides teaching training for university graduates. Those studying on a PGCE course are called pre-service or trainee teachers.

RS – Religious Studies

A GCSE examination course in the UK.

TES – Times Educational Supplement

A weekly publication aimed at UK school teachers. Within this thesis, the abbreviation refers to the TES website (<https://www.tes.com/uk/>). This is a popular website featuring teaching resources, jobs, and forums.

Chapter 1. Introduction and literature review

1.1 Introduction

1.1.1 Why evolution?

Evolution is widely recognised as one of the most misunderstood topics in biology (Linhart 1997). It can be a challenging subject to teach, particularly to school-aged students, due to the controversy and dispute it can provoke (Donnelly *et al.* 2009, Andersen *et al.* 2011). The importance of evolution is not fully recognised in schools and there are concerns over its unsatisfactory teaching. Many students have difficulty in accepting evidence for the theory of evolution and debate is currently in progress about how best to teach evolution in secondary schools (Alters and Nelson 2002, Dijk and Kattmann 2009).

The majority of research and concerns about teaching evolution originate in the USA; however there have been recent worries in the UK about public lack of understanding of and acceptance of evolution (Williams 2008). There have also been media reports which suggest creationism has been taught in UK schools and that religious-motivated groups have attempted to infiltrate science lessons. Regardless of whether there is any real reason for concern, there is no research within the UK that we are aware of which investigates evolution acceptance and understanding of secondary school-aged students, or factors that might impact understanding and acceptance. If concerns over evolution education are genuine, then research is needed to find the best way to improve the situation. If, however, there is less need for concern, UK students may provide an interesting research focus as to how best to teach evolution, which could be applicable not just within the UK, but in countries where evolution acceptance is more problematic.

1.1.2 Why genetics?

One research article has provided the motivation behind investigating the impact genetics knowledge may have on evolution understanding and acceptance. Miller *et al.*'s 2006 study reported responses of adult members of the public from 34 countries to the statement "human beings, as we know them, developed from an earlier species of animals". Responses were divided with much variation between

countries. Of the countries surveyed, Turkey showed the lowest acceptance, followed by the USA, with over a third of Americans firmly rejecting evolution. The UK had the sixth highest level of evolution acceptance, at over 70%. But what were of particular interest were the main reasons given for evolution acceptance: religion, political ideology, and genetic literacy.

This idea of a relationship between knowledge of genetics and acceptance of evolution has not been widely studied. It seems intuitive to hypothesise that good understanding of genetics should help understanding, and possibly acceptance, of evolution: DNA is the heritable material through which variation needed for evolution occurs. This hypothesis has provided the basis for this research and lead to questions such as: could something as simple as teaching genetics before teaching evolution, rather than teaching evolution followed by genetics, improve understanding and acceptance of evolution? Could making simple links between the two topics have a positive impact on learning? Genetics is a relatively neutral subject: it is not considered controversial in the ways that evolution might be. Could this be a means of improving evolution education without any concerns over potentially controversial issues?

1.1.3 Why me?

Following my undergraduate degree I trained as a secondary science teacher. For two years I worked in a large state school which had a high proportion of religious students. I was frustrated that when teaching theories such as evolution and the big bang some students simply refused to listen and complained as to why they had to learn these topics: to these students, their god had created the earth and all living organisms as they are today. Despite my attempts to explain different world views and the nature of science, I eventually succumbed to “because it’s on the exam board syllabus”. I was not helped by the fact that these topics tended to be the last within a module, taught at the end of the academic year, and that there was no time to deviate from the exam board specification. I felt unprepared by my teacher training course: I have no memory of these topics being covered, or of any guidance on how to manage students with strong religious or alternative beliefs which may contradict aspects of the curriculum. Overall I felt I had not done these topics justice and wish I’d been able to do better. This was one factor which

added to my leaving teaching. This project matches my interests and previous experiences and I hope that my research may have, or already have had, a positive impact on students and teachers.

1.1.4 Terminology

The terms ‘acceptance’ and ‘understanding’ are used throughout this thesis. Acceptance refers to agreement with an idea or theory or the recognition that a position is valid or correct (here, the theory of evolution). This is different from understanding, which refers to knowledge of a subject and practical application of this knowledge (here, evolution and genetics). Although it is appreciated that understanding is not the same as knowledge, the two terms are used interchangeably throughout this thesis; however this will be discussed further in Chapter 10.

Although the ‘UK’ (meaning the United Kingdom) is referred to within this thesis, research in schools has only been conducted within in England and Wales. The National Curriculum and examination requirements are different in other parts of the UK. Therefore, ‘UK’ should only be taken as relevant to England and Wales, within the context of this research.

The terms ‘focus groups’ and ‘group discussions’ are used synonymously. Similarly, ‘questionnaire’ and ‘survey’ also represent the same type of research instrument within the context of this research. Although ‘questionnaire’ tends to be used to describe the student questionnaire, and ‘survey’ to the describe the teacher survey, the two are ultimately the same things: the word ‘survey’ was introduced to the teacher survey as this was easier to promote online (it has less characters and sounds less formidable!). The terms ‘pre-service teacher’ and ‘trainee teacher’ are also used interchangeably.

The name ‘GEVOteach’ refers to this specific research project. The name was devised during an initial meeting between myself and my supervisors. It combines ‘evo’ from ‘evolution’ with a ‘G’ in reference to ‘genetics’, along with ‘teach’ to signify the importance of action research within classrooms.

1.1.5 Research questions

This project aims to investigate the part that knowledge of genetics can contribute to secondary school-aged students' understanding and acceptance of evolution.

Key research questions are:

1. How does knowledge of genetics contribute to students' understanding and acceptance of evolution?
2. What effect does teaching have on acceptance of evolution, knowledge of genetics, and knowledge of evolution?
3. Does academic ability affect acceptance of evolution and understanding of evolution and genetics?
4. What effect does changing the order in which topics are taught have?

In addressing these questions, other factors that might influence students' understanding and acceptance of evolution and understanding of genetics are considered, and questions raised relating to:

- How accepting of evolution are secondary school students in the UK?
- What knowledge of evolution and genetics do students have?
- What misconceptions do students have?

In addition, objectives of this project have been:

- To investigate teacher and pre-service teacher knowledge of evolution and genetics and how this may relate to evolution acceptance.
- To develop and implement teaching resources within schools.

1.1.6 Thesis structure

This introduction has so far provided a brief overview of the motivation for this study and the research questions. The remainder of this chapter examines the literature related to teaching evolution. Genetics in education and the teaching of both topics in the UK are also discussed. There is very limited research surrounding links between evolution and genetics and their possible importance in evolution education. This literature therefore provides a more general overview of evolution education. Chapter 2 describes the methodologies used in this study and

why they were chosen. In addition to outlining the research instruments used and how data collection was approached, findings from pilot studies are displayed and their influence on the main study detailed. Chapter 3 provides an analysis of the student questionnaire. It examines how effective these instruments are in testing acceptance of evolution and understanding of evolution and genetics.

Chapters 4, 5, and 6 analyse and interpret data collected from the student questionnaire. Chapter 4 examines student acceptance and understanding before evolution and genetics are taught in school, Chapter 5 considers data collected immediately after these topics were taught, and Chapter 6 studies retention data. Qualitative data from student focus groups are summarised in Chapter 7 and key themes identified.

Findings from teacher and pre-service teacher surveys are presented in Chapter 8. These are compared with those from the student questionnaire. Chapter 9 introduces the resource package and provides a tentative analysis of the impact of different resources in schools. Finally, Chapter 10 summarises the key findings of this research, considers how this research has contributed to knowledge within evolution education and implications for teaching. Limitations and challenges are discussed, and suggestions are made for future work.

Many chapters (particularly those pertinent to analyses and results) include a brief executive summary at the start, to aid readability, and end with a summary and implications for teaching. References from all chapters are found at the end of this thesis, followed by a short appendix which includes key research instruments such as the student questionnaire. A large volume of supplementary materials is contained in the attached disc. This includes details of administrative procedures, forms and letters. Also included are data related to the figures and tables displayed within the main body of the thesis, and further details of statistical analyses.

1.2 Literature review

1.2.1 Introduction to evolution acceptance, understanding, and education

Evolution is widely accepted as a central theory in biology. As Dobzhansky famously wrote, “nothing in biology makes sense except in the light of evolution” (Dobzhansky 1973, p.125), yet evolution is commonly regarded as one of the most misunderstood topics in biology (Ehrle 1960, Linhart 1997). Learning about evolution is important for understanding other areas of biology, such as developmental biology, physiology and ecology (Fail 2007, Dijk and Kattmann 2009) and for appreciating current challenges concerning the loss of biodiversity, diseases and food production (Banet and Ayuso 2003, Smith 2010). A good understanding of evolution is therefore needed for anyone working or studying biological and environmental sciences. A basic knowledge of evolution is also important for the general public so that the scientific and social implications of current issues such as GM crops, genetic screening and gene therapy can be appreciated and informed decisions made (Lewis and Wood-Robinson 2000, Banet and Ayuso 2003, Farber 2003).

Despite its importance, public understanding and acceptance of evolution is considered poor by many researchers (Alters and Nelson 2002). For example, a British Council (2009) survey of public attitude towards evolution found that just 45% of British adults surveyed had heard of Charles Darwin and knew something about his theory. In a survey of 34 countries compiled from data recorded between 1985 and 2005, just 40% of respondents from the United States of America accepted evolution (Miller *et al.* 2006). This caused much concern, particularly as acceptance of evolution was lower in the USA than in Japan and all the European countries studied (with the exception of Turkey). The results of such studies are worrying for science educators and there is currently much debate about how best to teach evolution, particularly at secondary school level.

The theory of evolution can be a controversial issue within education (Borczyk 2010, Hermann 2011). Strong opposition is well documented in the USA where creationists provoked the enforcement of laws banning the teaching of evolution existed for over forty years in Oklahoma, Mississippi, Tennessee and Arkansas

(Meikle 2011). Their enforcement included court cases against teachers found breaching these laws (Shotwell 1965). Disclaimers in biology textbooks asserting that evolution is ‘just a theory and not a fact’ were also implemented in some states (Bybee 2001, Borenstein 2006, Miller 2010). In addition, there have been reports of schools teaching intelligent design (Bowman 2008), suggestions of opt-out-policies which allow students to be excluded from evolution classes where they or their parents have religious objections (Scott and Branch 2008) and appeals for a variety of alternative theories to be taught alongside and given equal time to evolution (Aguillard 1999, Lerner 2000, Borenstein 2006). Although the vast majority of examples are from the USA, there have also been concerns about the impact that religious movements or strong cultural and social traditions may have on evolution education in other countries, including Northern Ireland (McCrory and Murphy 2009), Poland (Borczyk 2010), South Africa (Abrie 2010), Tunisia (Aroua *et al.* 2009) and Turkey (Deniz *et al.* 2008).

Within the UK, teaching the theory of evolution has rarely caused such extreme actions or public outcry as seen in the USA. However, the issue made headlines in 2002 when claims were made that creationism was being taught in schools. The government funded academy, The Emmanuel College, Gateshead, was reported to be teaching creationism in science classes with school administrators and the Head of Science openly accepting creationism (Branigan 2002, Williams 2008, Allgaier 2010). There have also been attempts by creationist movements to infiltrate science teaching, including the *Truth in Science* organisation, which distributed promotional DVDs to all state secondary schools in the UK in 2006. These DVDs challenged Darwinian evolution, supported intelligent design, and promoted a ‘teach the controversy’ approach to instruction (Williams 2008). It is unknown how many schools actually used these materials, or in what way. Much of the media interest in evolution education and creationism is focused on singular examples and anecdotal evidence and there is no real consensus as to whether there is any nationwide problem.

Perhaps because of the emotive nature of its controversies, the importance of evolution is not fully recognised in schools and there are concerns over its unsatisfactory teaching (Alters and Nelson 2002, Dijk and Kattmann 2009).

Research suggests that students' grasp of evolution is often poor and does not always agree with scientific understanding of the theory (Bishop and Anderson 1990, Woods and Scharmann 2001, Banet and Ayuso 2003, Farber 2003, Andrews *et al.* 2011). Although the same could be said of any subject, there are concerns that evolution is somewhat unique in biology in that this lack of understanding may be attributed to a lack of acceptance of evolution. The impact of this poor knowledge on higher education is worrying, with many university lecturers reporting low levels of understanding among first year undergraduate students (e.g. Jakobi 2010). This may also be the reason why public understanding of evolution is also considered poor by many researchers (Alters and Nelson 2002).

Given the biological and social importance of evolution, it is vital that students have a good introduction to the topic and there is currently much debate about how best to teach evolution at secondary school. Here, the main challenges to teaching evolution are examined, and possible approaches to teaching evolution are discussed.

1.2.2 Challenges to understanding, accepting and teaching evolution

Biological evolution is widely recognised as a difficult subject to teach, particularly to school-aged students, due to the controversy and debate it can incite. It can be a difficult topic for students to understand and accept, often due to conflicts with personal beliefs and cultural traditions (Donnelly *et al.* 2009; Andersen *et al.* 2011). Hildebrand *et al.* (2008) use Schwab's commonplaces model of curriculum (Schwab 1973, Schwab 1983) to conceptualise evolution learning environments as being a dynamic exchange between students, teachers and subject matter, within a contextual milieu or social environment within which teaching and learning occur. Each of these components has equal importance and each will impact the others. The factors that might influence students' understanding and acceptance of evolution, teachers' approaches to teaching evolution, and aspects of evolution which may prove challenging, are discussed here.

1.2.2.1 Student factors

There are many factors that may influence students' understanding and acceptance of evolution. Understanding and acceptance of evolution are not the same thing. It is often assumed that understanding will lead to acceptance, but there is a complicated relationship between the two which is not fully understood (Cobern 1994, Deniz *et al.* 2008). Studies by Rutledge and Warden (2000) and Deniz *et al.* (2008) suggest a positive correlation between understanding and acceptance of evolution; however, other studies (e.g. Bishop and Anderson 1990, Brem *et al.* 2003, Sinatra *et al.* 2003, Ingram and Nelson 2006) have shown little or no relationship between the two. The following factors are linked to students' backgrounds, beliefs and prior conceptions and are likely to influence how students approach their evolution education, and their opinions of the topic prior to instruction. They may also predict how responsive a student may be to instruction and to some extent, whether education may be able to alter these prior conceptions.

Religious orientation. Religiosity has been negatively linked to scientific literacy, even when evolution is not included in studies. For example, Sherkat (2011) found that those with strongly religious beliefs have significantly lower scientific literacy levels than secularists, and that religious factors were more substantial than demographic factors including gender, ethnicity, and income. However, evolution is considered unique among scientific theories (perhaps with the exception of the origin of the universe and big bang theory) for the impact that religious beliefs can have on its understanding and acceptance (Alters and Nelson 2002). There is much research and comment on whether science educators should engage with issues surrounding science and religion (for example, Reiss 2008), the relationship between evolution and religion, and the ways in which students perceive compatibility between the two (for example, Dagher and BouJaoude 1997, Thagard and Findlay 2010, Taber *et al.* 2011, Yasri and Mancy 2014).

The negative relationship between religious beliefs and acceptance of the theory of evolution is well documented. Many teachers and researches report the difficulties of changing strongly held religious beliefs with studies suggesting that instruction has little or no impact. Lawson and Worsnop (1992) found that highly

religious school students in Arizona were less likely to accept evolution prior to teaching of the subject, and were less likely to move towards acceptance after teaching, than those students who were accepting of evolution. Similarly, studies of USA undergraduate students by Lawson (1983) and McKeachie *et al.* (2002) found that education had little impact on students with alternative prior beliefs and that “belief in evolution” was a strong predictor of understanding evolution. Deniz *et al.* (2008) discovered a comparable negative relationship between religion and evolution acceptance among Turkish pre-service biology teachers. However, other studies have found no such links between belief and knowledge, or varying levels of reject of the theory of evolution due to religious beliefs, suggesting that acceptance or rejection of evolution does not necessarily influence understanding (Bishop and Anderson 1990, Brem *at al.* 2003, Ingram and Nelson 2006), Hokayem and BouJaoude 2008).

The extent of religious belief in classrooms, and the implications this may have for evolution education, are likely to vary between countries and school types (for example, secular versus faith school). It is important to recognise that even where students are religious or have had a religious upbringing, this does not necessarily mean rejection of evolution. For example, in an American study, Woods and Scharmann (2001) found that 32% of high school students interviewed about their understanding and acceptance of evolution reported conflict of some sort between evolution and what they were raised to believe at home, but only 18% stated that evolution conflicted with their personal beliefs. Yasri and Mancy (2014) explored different perspectives from high school students in Thailand. For some students, evolution was compatible with their religious beliefs, but for others, evolution was completely incompatible. However within these positions, there were large variations in the extent to which evolution contrasted with or complemented students’ personal views.

Reasoning level. A number of studies suggest that logical reasoning skills affect students’ ability to understand evolution and gain knowledge (Lawson and Thompson 1988, Lawson and Weser 1990, Lawson and Worsnop 1992, Banet and Ayuso 2003), acceptance of evolution (Woods and Scharmann 2001, Deniz, Donnelly *et al.* 2008) and the extent to which non-scientific beliefs may be altered

by instruction (Lawson and Weser 1990, Alters and Nelson 2002). Students with better reasoning abilities have been found to hold fewer misconceptions about evolution, whereas mental capacity, verbal intelligence and cognitive style have not shown any significant correlation to the number of misconceptions held (Lawson and Thompson 1988, Lawson and Weser 1990). Lawson and Weser (1990) also found that students who were less skilled at reasoning were less likely to change their views following instruction, however, the importance of other factors, such as personal beliefs, were more apparent here.

Acceptance of evolutionary theory. Acceptance of evolutionary theory may impact how students approach learning about evolution and their learning experience (McKeachie *et al.* 2002). Donnelly *et al.* (2009) explored how student acceptance related to views on evolution and evolution teaching. They found that students who accepted evolution were more likely to enjoy and feel comfortable learning about evolution, than those who rejected the theory (100% compared to 67%). Studies have also shown that acceptance varies for different aspects of evolution, with human evolution being the least accepted aspect of evolution (Rutledge and Warden 2000, Donnelly *et al.* 2009).

Many studies suggest more than 50% of students accept evolution or evolution combined with religious ideas (Bishop and Anderson 1990, McKeachie *et al.* 2002, Ingram and Nelson 2006). Non-acceptance of evolution does not necessarily imply rejection of evolution (Donnelly *et al.* 2009). Ingram and Nelson (2006) found that the majority of students held positive attitudes towards evolution and that these became more positive following instruction, especially among students who were previously 'undecided'. However, acceptance of evolution does not necessarily indicate understanding of evolution.

Authority figures. Acceptance of evolution may be linked to respect for authority figures such as parents or teachers (Donnelly *et al.* 2009), personal relationships with parents, teachers and friends (Woods and Scharmann 2001) or perceptions of teachers (Hildebrand *et al.* 2008). Students may move their views to be closer to those of people they have respect for or admire, or may feel peer pressure to have

similar views. The media may also have an impact on students perspectives (Woods and Scharmann 2001).

Perception of the impact of evolution theory. The social and personal implications of evolution present an issue for scientists and philosophers, and can be disturbing and objectionable (Allchin 1999). Brem *et al.* (2003) investigated the perceived impact of evolutionary theory of college-educated adults. They found that evolutionists were less likely to consider that acceptance of evolution would have a social or personal impact. However, similar negative perceptions were made by both evolutionists and creationists, and included increased selfishness, racism and decreased sense of purpose. Moreover, the strength of perception of these negative consequences increased with knowledge of evolution.

There are a number of other factors which have been suggested as impacting students' understanding and acceptance of evolution. These include parents' educational level, scientific epistemology, and view of the nature of science (Donnelly *et al.* 2009), worldview (Hermann 2008), and locus of control (Woods and Scharmann 2001). However, there is limited research into these factors. Demographic factors such as gender have also been suggested, but very little or no difference as been found between these factors and understanding and accepting of evolution (Ingram and Nelson 2006). Clearly, many of these factors are interlinked and the impact of particular factors may vary from student to student (Hermann 2008). Deniz *et al.* (2008) discovered that studying factors in a multivariate context was more informative than examining factors in isolation.

Despite the differing beliefs and opinions, Donnelly *et al.* (2009) found that the majority of students thought evolution should be taught in school. The main reasons given as to why evolution is important to learn were that it helped to understand other views, learning about evolution doesn't require acceptance, it can help students to form their own views, it has much supporting evidence, it is central to the study of biology and the theory is supported by scientists. Reasons students gave for not being taught evolution included that it may clash with or confuse students' religious beliefs.

1.2.2.2 Teacher factors

Teachers obviously have their own personal beliefs and views of the world. These factors may impact how (and indeed, if) evolution is taught (Deniz *et al.* 2008, Goldston and Kyzer 2009). Religious beliefs and acceptance of evolution appear to be key factors (Trani 2004), with numerous studies suggesting creationist views exist among science teachers (e.g. Moore and Kraemer 2005). McCrory and Murphy (2009) surveyed 112 pre-service teachers in Northern Ireland and found that over 25% disputed the common ancestry of life, and that more than 20% doubted the evidence for human evolution. Moore and Kraemer (2005) found almost 25% of teachers in Minnesota believed creationism to have a valid scientific foundation. However, Zimmerman (1987) found that 75% of biology teachers accepted the theory of evolution. Less is known about how these beliefs impact teachers' instructional approaches (Moore and Kraemer 2005). In addition to this, and those described in student factors, teaching of evolution may be affected by a number of other factors.

Content knowledge. There are many studies which suggest that not all teachers fully understand the theory of evolution (e.g. Zimmerman 1987, Goldston and Kyzer 2009, Nehm *et al.* 2009). A South African study by Sanders and Ngxola (2009) found that 49% of teachers surveyed were concerned that their knowledge of evolution was inadequate. In secondary schools, evolution may not always be taught by a biology specialist. Where this is the case, subject knowledge may be poor or superficial. Even where a teacher has previously studied for a biology-related degree and teacher training course, this does not necessarily mean that the teacher has studied evolution in much depth or that they are equipped to teach evolution to students. Some teachers may lack confidence in their knowledge, which could cause concern or embarrassment, or feel that their knowledge is out-of-date. These concerns may cause teachers to avoid or minimise their teaching of these topics (Griffith and Brem 2004). Teachers may also be unaware of legal issues related to teaching evolution (and creationism) (Moore 2004).

Perceived opinions on evolution. Some teachers recognise that evolutionary theory conflicts with the beliefs of their school community. They may consider evolution to be disapproved of or even unmentionable within their school

(Goldston and Kyzer 2009). Teachers are likely to approach evolution with caution or may even avoid teaching it (Borenstein 2006). Teachers may not cover the full curriculum stipulated by government standards or examination boards, or some may present evolution in a superficial manner or hidden among other topics. Some teachers present evolution as ‘only a theory’, or alongside other theories, such as creationism. These diversions from the curriculum may be due to teachers’ own beliefs, but may also be due to pressure from students, parents, other teachers, the school community and administrators (Deniz *et al.* 2008; Goldston and Kyzer 2009). Zimmerman (1987) found that 10% teachers surveyed in Ohio had experienced pressure not to teach evolution, and 11% had experienced pressure to include creationism in their lessons. This proportion rose to 20% in a similar study by Van Koevering and Stiehl (1989) in Wisconsin.

Time constraints. All teachers are only too aware of the time constraints placed upon them, especially during important exam phases. Teaching of evolution (like almost all secondary school subjects) is constrained by lesson times (dictated by the government and school), and by exam boards (a set number of topics to get through in a limited amount of time). Student performance in exams is often seen as a reflection of the quality of a school and its teachers. Teachers might therefore ‘teach to the test’ or focus on topics that are more likely to be assessed in formal examinations. Spending too long on topics such as evolution, which do not usually demand many hours teaching time, could be viewed as disadvantageous to student achievement, even though this approach is clearly detrimental to scientific understanding (Eldredge 2009). However, time spent on a topic may also be related to a teacher’s personal opinions on the subject, with teachers who accept evolution being more likely to spend more time teaching about evolution (Deniz *et al.* 2008).

1.2.2.3 Subject factors

The difficulty in teaching evolution at secondary school level has been well documented (e.g. Taskin 2011). This is due, in part, to the controversies it can cause, and the difficulties that students can have with understanding the concept. It has even been suggested that evolution should be taught at a higher educational level, as it is too controversial or difficult to teach in secondary school, and

because school level understanding is so poor. However there has been much opposition to this (Keim 2008, Mead and Branch 2011).

Controversies. By the time a scientific theory enters the national curriculum, it is expected to have gained acceptance from the majority of scientists. Evolution is no different. It is controversial due to potential conflict with religion and personal beliefs (Hermann 2008). It is important that these potential controversies are recognised by science educators, but it must be understood that the theory of evolution is, scientifically, not controversial. The controversy arises outside of the scientific community, often in the form of parents and school administrators who may not have a scientific background (Hildebrand *et al.* 2008).

Misconceptions. Despite evolution being such an important and central theme in biology, many students have difficulties in understanding the concepts of evolution by natural selection (Bishop and Anderson 1990, Nehm and Reilly 2007, Prinou *et al.* 2010, Pazza *et al.* 2009) and student knowledge, even after instruction, does not always agree with that of evolutionary biologists (Deniz *et al.* 2008). Misconceptions may be linked to many factors, including age, nationality, educational level, and prior instruction, or be may based on religious beliefs or myth-based ideas (Alters and Nelson 2002, Geraedts and Boersma 2006). Even students who are high achievers and appear to understand evolution may have actually just ‘learnt for the test’ and lack a basic understanding (Alters and Nelson 2002). Such misconceptions can be difficult to change and can seriously hinder a student’s progression at a higher academic level.

There are many misconceptions which are commonly reported in studies of school and university students’ understanding of evolution. Frequently cited examples include student tendency to use anthropomorphic terms and teleology in their definitions of evolution (Woods and Scharmann 2001, Alters and Nelson 2002), and Lamarckian concepts, such as it is individuals that change and that these adaptations happen as a direct result of environmental changes (Brumby 1984, Alters and Nelson 2002, Geraedts and Boersma 2006, Andrews *et al.* 2011). Terms such ‘evidence’ and ‘theory’ are frequently misunderstood, as is the process of scientific enquiry and the nature of science (Bybee 2001, Alters and

Nelson 2002). Students often confuse the scientific meaning of words such as 'adapt' and 'fitness' with their everyday meanings (Alters and Nelson 2002). Misconceptions also exist among teachers, and may be inadvertently taught to students. For example, in a survey of biology secondary school teachers, 22% thought that evolution involved a purpose and advancing towards "higher" life form (Zimmerman 1987). Difficulties in grasping geological time are common among students and teachers (Trend 2000, Trend 2001, Dodick and Orion 2003, Catley and Novick 2009, Dijk and Kattmann 2009). Clearly none of these misconceptions help students' understanding and may also impact their acceptance of evolution.

Time and Syllabus constraints. Due to curriculum demands and school timetabling, evolution is often reduced to a quick summary and may receive just a few hours of lessons in secondary school classrooms (Eldredge 2009). Related topics might be taught weeks or even months apart, with no link made between lessons (Lewis and Wood-Robinson 2000). Many education researchers support the idea of conceptual change and consider that evolution can take time for students to understand and accept (Sinatra *et al.* 2008).

Although evolution is of great importance in biology, this is not always true in secondary schools. Many school students have problems in understanding and accepting evolution, and many teachers find teaching the topic challenging. Clearly there is a need for educators to appreciate these challenges and be aware of them when planning teaching and learning activities.

1.2.3 Approaches to teaching evolution

There is currently much debate as to how best to teach evolution. Many academic studies highlight the factors which impact understanding and acceptance of evolution and common misconceptions which students hold, but few present tried and tested, effective teaching and learning strategies that focus specifically on teaching biological evolution to school-age students (Geraedts and Boersma 2006). Both Cobern (1994) and Donnelly *et al.* (2009) suggest that biology teachers need to be aware of the differences in teaching for understanding and teaching for acceptance of evolution, and have suggested that it is morally wrong

to teach for acceptance. It is clear that with so many different opinions and factors influencing students' understanding and acceptance of evolution, no single strategy will be able to overcome all of the barriers to learning that exist (Andersen *et al.* 2011).

1.2.3.1 Approaches to teaching a controversial topic

Evolution is not a scientifically controversial topic, but can be viewed as controversial due to non-scientific considerations, such as social, political and religious issues. Most teachers are aware of these controversies and may plan their teaching of evolution around these controversies. The approach taken to teaching evolution is likely to be based on individual teachers' experience of teaching controversial issues and concerns about addressing controversies in their classrooms (Van Rooy 1999) and their training in dealing with alternative theories (Cleaves and Toplis 2007), but may also be influenced by their own personal beliefs and their view of the beliefs of their students (Scharmann and Harris 1992, Hildebrand *et al.* 2008). How (and indeed, if) these non-scientific controversies should be approached in the scientific classroom is a topic of active debate (Hermann 2008).

Avoidance approaches. These approaches aim to avoid any controversy or conflict in the classroom and are also referred to as a 'selective teachers' approach by Griffith and Brem (2004). Avoidance strategies may include omitting the teaching of evolution completely, leaving evolution until the end of the school year or term hence limiting the time spent on the subject, not mentioning 'evolution' specifically, or teaching non-controversial aspects of the topic thus avoiding any potential conflict (Shotwell 1965, Scharmann 1994, Nickels *et al.* 1996, Griffith and Brem 2004, Hildebrand *et al.* 2008). Avoidance may be used as a coping strategy for teachers whose religious beliefs conflict with the theory of evolution, or where teachers are particularly concerned about student and community views on evolution (Griffith and Brem 2004). Although in the short term this approach will serve its purpose in deflecting conflict, it does not prepare students for their future studies or encounters with evolution, or help them tolerate different view points (Scharmann 1994). Avoidance approaches are likely to be the most detrimental to students as they may negatively impact a student's

education, both in their examination results, and in their fundamental understanding of science and the natural world. Students will be able to continue to accept any misconceptions, without challenge (Nickels *et al.* 1996). Given teacher accountability and exam specifications including evolution, it is unlikely that many teachers omit evolution completely (Hildebrand *et al.* 2008); however, Rutledge and Warden (2002) surveyed 989 Indiana school teachers and found that 43% of these teachers classified their coverage of evolution as ‘avoidance’ or ‘briefly mentioned’. This approach may also be adopted where teachers do not feel they have the experience or skills necessary to tackle the controversy (Hermann 2008). Scott and Branch (2008) also criticise the avoidance of evolution by students through opt-out-policies. These allow students to be excluded from evolution classes due to religious objections. Avoidance by students will negatively impact their learning, as they will miss out on a central theory in biology, their fellow students’ learning, whose lessons will be disrupted, and also their teachers, who will be unable to fulfil their duty to teach the students (Scott and Branch 2008).

Dogmatic approaches. Known as ‘dogmatic corrosive’ (Hildebrand *et al.* 2008), ‘scientific teacher’ (Griffith and Brem 2004), or ‘advocacy’ approaches (Hermann 2008), dogmatic approaches focus purely on the scientific aspects of evolution and do not allow any discussion of controversial social issues or religion in classrooms. This should reduce the chance of disruption or conflict, especially where class focus is on exam success. Teachers who adopt this approach may not want to waste already limited classroom time covering topics that will not appear in exams, and usually have a strong sense of what should and should not be included in science lessons (Griffith and Brem 2004). A dogmatic approach may involve teaching evolution as ‘absolute truth’ and denying any controversy, regardless of student beliefs or prior conceptions. (Hildebrand *et al.* 2008). This approach could force students into thinking that they have to choose between evolution and their own personal views (where these differ from those being taught). Scharmann (1994) believes that students should never be placed in this perceived dilemma of having to choose between the two and it could be uncomfortable and isolating for students. This approach may be viewed as corrosive as it could corrode the student-teacher relationship (Hildebrand *et al.*

2008). An alternative view is that this could actually be empowering if a student understands that the teacher is discussing evidence-based scientific fact and accepts evolution, regardless of what they have thought or learn previously.

Passive approaches. Synonymous with ‘conflicted teacher’ (Griffith and Brem 2004) and ‘affirmative neutrality’ approaches (Hermann 2008), passive approaches may be utilised by teachers who struggle with their own beliefs, are concerned about the potential impact of their teaching and students’ wellbeing, or worry about classroom conflicts. A teacher may present a number of alternative views, but not disclose their own opinions or beliefs (Hermann 2008). Teachers adopting a passive approach may tell students that they have to know about evolution for their exams, but that they don’t have to believe it. Teachers may talk to students individually to reassure them or forestall any conflict, or convince students that they won’t try to change their beliefs (Griffith and Brem 2004, Hildebrand *et al.* 2008). This approach might be acceptable if evolution is taught with the goal of understanding, not acceptance (Smith and Siegel 2004), then it could be argued that the passive approach is not detrimental, especially if discussion of the nature of science is included. However, this approach could demean the scientific status of evolution and undermine the value of science, hence damaging the student-science relationship (Hildebrand *et al.* 2008).

Teaching about the controversy. These approaches typically involved a ‘balanced’ approach to teaching evolution (Hildebrand *et al.* 2008). Teachers may describe why evolution is viewed as controversial by some people, such as religious groups, and present alternative theories to students. They will allow students to make up their own minds and express their views (Hermann 2008, Hildebrand *et al.* 2008). The extent to which alternative views are investigated or taught will vary between teachers, and evolution and religion will not necessarily be given equal time or coverage (Brem *et al.* 2003). This approach has received some support from science educators (e.g. Dagher and BouJaoude 1997, Lawson 1999, Nord 1999), who think that students should be involved in the debate. Nord (1999) suggests that this debate should include all of science and religion, rather than just evolution and specific views such as creationism. He believes that by ignoring the relationship between science and religion, teachers are depriving

students of intellectual challenge. This approach appears to be utilised quite frequently in secondary education. For example, Zimmerman (1987) found that over 20% of high school biology teachers surveyed included creationism in their courses (over 70% of these viewed creationism as favourable) and that 25% of teachers thought creationism should be taught in science lessons.

A balanced approach is often popular with students. Some suggest that evolution education would be improved by the inclusion of alternative theories in science lessons (Donnelly *et al.* 2009) or that not allowing access to alternative views so that they may formulate their own ideas could be classed as censorship (Brem *et al.* 2003, Hermann 2008, Donnelly *et al.* 2009). Hildebrand *et al.* (2008) suggest that this approach is likely to engage and motivate students, but question whether learning outcomes will be achieved and there is no evidence to suggest that understanding or acceptance of evolution may be maximised by this approach.

Although this ‘teaching about the controversy’ approach is different from the ‘teach the controversy’ approach, which largely has intelligent design and creationism roots, care must be taken as to how controversy is taught and discussed in classrooms. Alternative views may not be scientific, and therefore are not able to be tested or evaluated in a scientific manner. Spending science lesson time on non-scientific ideas may give students the notion that such ideas are equal to scientific theory or in direct competition. This approach could lead to heated conflicts if not managed carefully, and outright debates about the topic have been discouraged by a number of researchers (such as Hildebrand *et al.* 2008) as they may trigger further conflict. Furthermore, school science classes are often constricted by the curriculum and are therefore unlikely to have time to fully explore and understand the controversies, especially if these are not relevant to exams. Hildebrand *et al.* (2008) question whether secondary school students have the capacity to fully understand the debate or whether misconceptions will really be helped. Depending on the extent to which this approach is taken, discussion could turn into conflict and a teacher’s professional judgement could be questioned.

Hildebrand *et al.* (2008) and Hermann (2008) suggest approaches which are similar to a balanced approach, but which do not directly teach alternative views.

Hildebrand *et al.* (2008) have designed a ‘proactive, pro-social management’ approach which neither avoids or ignores the controversy, but does not deal with the controversy in a way that is equal to science. This approach is comparable to teaching evolution alongside the nature of science. Similarly, Hermann (2008) promotes a ‘procedural neutrality’ approach (after Bridges 1986) where controversy is acknowledged but not directly taught. This approach allows students to discuss their views with the aim of widening their worldview and empathy. Although these ideas sound plausible, there is limited guidance as to how these approaches could actually be used in a classroom situation, or research into whether they are effective strategies for dealing with controversy.

There are strong views as to if or how the potential controversies related to evolution could be dealt with in science lessons. A wide variety of strategies are currently in use, however there has been limited research into the extent that different strategies are used, or into the impact of these approaches (Hermann 2008). Griffith and Brem (2004) state that teachers must balance their professional duties as with the concerns and possible demands of their community, and their own personal beliefs. Choices made to negotiate controversy may actually make the situation worse, and although in the short term debate over the controversy may be reduced in the classroom, teaching and learning may be less effective in the long term (Hildebrand *et al.* 2008). Hermann (2008) suggests that rather than considering understanding, effectiveness of teaching should be measured by the amount of conflict caused by the instructional approach, and students’ tolerance for other views of evolution. Clearly there is a need for teaching programmes that are sensitive to potential controversy, but that show scientific integrity. Individual teachers may not always have the time or knowledge to do this.

1.2.3.2 Evolution teaching strategies: prior knowledge, content and context

Many suggestions have been made as to what should be taught as part of an evolution course at a particular academic level, such as during secondary school. Alters and Nelson (2002) suggest it may be better to decrease content, so that

students could have better understanding of fewer topics. However, for the majority of secondary school biology students studying for qualifications which follow a prescriptive exam specification, this will dictate what must be taught, and time constraints often limit any teaching beyond this. However it is up to individual schools and teachers to decide *how* evolution is taught and there are many different opinions on this.

Basic biological knowledge. Many educators advocate the need for students to have good understanding of many basic biology topics before evolution can be taught (Ehrle 1960, Banet and Ayuso 2000, Banet and Ayuso 2003). This approach appears sensible: there is limited point in attempting to discuss similarities and differences between species if students have no basic understanding of anatomy or physiology. Ehrle (1960) believes that students need to be given all the evidence, and that then they will be able to accept the theory of evolution. Fail (2007) agrees with this perspective and also suggests that most biology topics cannot be fully appreciated without a basic knowledge of evolution, and that basic biological knowledge and evolution knowledge should complement each other. Students' views of the natural world and themselves may need to change before they can thoroughly grasp evolution. Ehrle (1962) and Eldridge (2009) recognise that students often have problems with thinking of themselves as animals, and that this can lead to misunderstandings and distrust when human evolution is taught. Obviously, knowledge of many biological topics and interpretations of the natural world cannot be taught or changed as part of an evolution course. They should be learned during a student's science education, in preparation for learning the topic of evolution. Banet and Ayuso (2000 and 2003) suggest that important, relevant aspects should be recapped immediately prior to evolution learning.

Evolution as a central and unifying theme. Science and education researchers (including Fail 2007, Dijk and Kattmann 2009) suggest that evolution should be taught as a central and unifying theme in biology, yet this is not demonstrated in current secondary school education where evolution is usually taught as only one topic among many and evolution is rarely linked to other topics. Unless drastic

changes are made to the secondary school science curriculum at all educational levels, this is unlikely to be a realistic teaching strategy in schools.

Nature of science. Within scientific research, the process of enquiry, gathering evidence, and testing theories is of key importance. Within science education, scientific enquiry is included in the National Curriculum in the UK (QCA 2007). However, it is often compartmentalised into coursework or a unit of its own, and students may not appreciate its workings throughout other aspects of biology, and their understanding may not always be comparable with the scientific community. Many researchers (including Bybee 2001, Farber 2003, Eldredge 2009, Pazza *et al.* 2009, Kampourakis and McComas 2010) suggest that the nature of science could be taught within the context of evolution. By teaching evolution through the nature of science, there will be key opportunities to discuss what is meant by a theory, facts and evidence, and allow students to formulate their own ideas and improve their skills. This approach may also help students to understand the differences between science and religion, and the use of terms such as *acceptance* and *belief* (Griffith and Brem 2004, Hermann 2008). Farber (2003) is particularly critical of current methods of evolution education in secondary schools where most courses and textbooks follow a similar sequence of events (pre-Darwin, Darwin, theory of evolution by natural selection, then fossil evidence). They worry about the impression of science that this conveys: that scientists make a claim, and then build a ‘fortress of evidence’ around it. This is opposite to how science works and misses important opportunities to teach scientific enquiry. Problems with adopting this approach include time limitations: there may be no time to teach the nature of science as part of an evolution topic unless a syllabus specifically allows this. Worryingly, Scharmann and Harris (1992) also have concerns that not all secondary school teachers have an adequate understanding of the nature of science.

Constructivist approach (challenging misconceptions). It is very difficult for students to learn new concepts if they already have their own explanations for scientific processes, yet teachers often plan and teach their lessons with little or no thought to conceptions that students may already have on the subject (Alters and Nelson 2002, Sinatra *et al.* 2008). A constructivist approach allows students to

actively examine, argue and test their prior conceptions, and where necessary, this prior knowledge can be restructured and brought closer to what is generally accepted by the scientific community (Alters and Nelson 2002, Banet and Ayuso 2003, Andrews *et al.* 2011). This approach promotes conceptual change and is supported by a many education researchers (e.g. Banet and Ayuso 2003, Deniz, Donnelly *et al.* 2008, Sinatra, *et al.* 2008). However, Geraedts and Boersma (2006) evaluate studies which use this approach as ‘only moderately successful’. They question the need for this strategy, suggesting that many misconceptions do not require conceptual change and that Lamarckian concepts are often overemphasised.

A clear limitation of this method for teachers is time constraints. For example, if there are 30 students in a class, each with their own ideas, it will be very difficult for teachers to gauge the ideas of every single student in the few hours of biology classes they may have in a week. Where prior conceptions are investigated, it is possible that time may be focused on alternative theories and that unsuitable discussions or conflict could arise. It is also questioned whether the majority of school-ages students are capable of maturely examining their own beliefs and comparing them to standard scientific ones. Due to the relatively short time students study evolution for during secondary school, there may not be enough time for conceptual change to occur.

Guided reinvention. Geraedts and Boersma (2006) have designed a teaching and learning strategy for secondary school students where, by answering a series of questions, students should be able to logically reinvent Darwin’s theory of evolution by natural selection. Results show that the majority of students using this strategy developed Darwinian or neo-Darwinian concepts and that very few Lamarckian explanations were given. This activity took place over two 50 minute lessons, however, the activity involves a lot of student thinking and discussion time, independently and in small groups. Therefore good behaviour and communication skills are essential. This may provide an interesting challenge to some students, but is plainly not suitable for all classes. Farber (2003) uses a comparable ‘case study approach’ activity which is based on answering a set of questions, similar to those that Darwin would have been presented with. Through

examples of evidence, students are able to formulate their own theories. This is closely linked to the nature of science and may be incorporated into that strategy (Farber 2003).

Approaching genetics and evolution jointly. There are numerous supporters of linking the teaching of evolution with genetics, but for the most part, this is based on opinion (Smith *et al.* 2009, Weiss and Dreesmann 2014). A rare exception is found in Banet and Ayuso (2003) who devised a teaching programme for genetics followed by evolution. This approach began with general ideas on characteristics and inheritance followed by chromosomes, genes and alleles, and this was then linked to intraspecific diversity and natural selection. It was trialled with 83 secondary school students in Spain. Overall, improvements in students' understanding of evolution and genetics were reported, although some Lamarckian misconceptions prevailed. However, these results may have been linked to the constructivist teaching programme, rather than the order of topics or any links made between them, but clearly there is scope for further work related to this.

Geraedts and Boersma (2006) do not view this approach as helpful, suggesting that as Darwin didn't know about genetics, it should not be necessary for students to know about them within the context of evolution either. However, this argument would seem counter-productive as the study of genetics does provide further understanding of and evidence for the theory of evolution.

Introduction at an Earlier Accademic Stage. Researchers (including Fail 2007, Chanet and Lusignan 2008, Hermann 2011, Weiss and Dreesmann 2014) suggest that evolution should be introduced at an earlier educational stage. This would be a way of increasing available teaching time for evolution and would seem a sensible suggestion, especially when considering time needed for conceptual change. Focus has also turned to primary schools where Chanet and Lusignan (2008) argue that if and when questions arise about the origins of life and humans, it is the job of the teacher to explain this scientifically to students, but that in a manner appropriate for the age of the students. A number of evolution-related activities for primary school students (4-11 year olds) have been designed and

trialled. Chanet and Lusignan (2008) produced simple activities based on classification for younger students, and more complicated activities, including interrelationship trees, for older students. Nadelson *et al.* (2009) developed lessons to teach primary school children some elements of speciation and adaptation. Feedback on both of these teaching programmes has been generally positive, but there is limited scientific evidence to support this. Evolution is complex and teaching it in primary schools can be difficult, especially as primary teachers are not subject specialists. It may be met with protest and challenge (Chanet and Lusignan 2008).

Many of these suggested strategies are closely linked or compliment each other. A combination of these strategies may assist in teaching evolution effectively. However, constraints placed upon teaching time and by the curriculum will limit the extent to which certain approaches can be used. All of these approaches lack empirical trials and clearly this is an area where further research is needed.

1.2.3.3 Teaching activities and resources

As is true for most subjects and topics taught at secondary school, evolution education researchers recommend teaching activities which encourage active learning through investigations and discussion, and which interest and motivate students (Alters and Nelson 2002, Fail 2007). Some advocate the importance of learning experiences outside of school, such as field trips and museum visits, especially where these allows students to see evidence at first hand (Diamond and Evans 2007, Eldredge 2009). The availability of resources may be dependent on school finances, teacher time and motivation, and choice of activities used may reflect teacher preference and student behaviour. This varies greatly between classes, teachers, and schools.

The most accessible and commonly used resources are books and the internet. Textbooks are widely available and used to some extent by most teachers. Many schools use books which are specific to the exam board studied. Zimmerman (1987) found that 78% of biology teachers surveyed were satisfied with evolution coverage in textbooks; however many researchers are very critical of the evolution content in biology textbooks. Criticisms include flaws in explanations,

over-simplicity of explanations, brevity of coverage, lack of up to date information, and emphasis on rote learning. (Linhart 1997, Alles and Stevenson 2003, Geraedts and Boersma 2006, Rees 2007). Few suggestions have been made to evolution-specific book related work beyond usual textbook work. Fail (2007) suggests the use of Darwin's and Wallace's texts in classrooms as a compare and contrast exercise. Given the varying literacy levels likely among school-aged students, time constraints, and the unlikelihood of Wallace being mentioned in any exam syllabi, this idea appears inaccessible and unlikely to be an effective way of learning about evolution for most students. Indeed, anecdotally a trial of critical analysis of *The Origin of Species* for second year undergraduates proven to be a futile task, not least because of the inaccessible 19th century language (Laurence Hurst, pers. Comm.). However, the Darwin Correspondence Project (<https://www.darwinproject.ac.uk/>) is currently creating learning activities around the works of Darwin and produces free, cross curricular resources for a variety of school levels. It will be interesting to see how such projects are evaluated and used within schools.

The internet is used increasingly in education to provide free, up to date resources for teachers and students. The main problem with these resources are concerns over reliability of information (Andersen *et al.* 2011), especially in the case of evolution with many anti-Darwin movements active on the internet, but not obvious in their orientations (for example, the 'Truth in Science' website). The vast amount of information available and limited time teachers have to search for suitable activities may also limit use (Baggott La Velle 2000, Wuerth 2004). There has been some focus on providing trustworthy and user-friendly websites for evolution education of students and the public, such as the Danish website Evolution 2.0/Darwin (Andersen *et al.* 2011). Other educators have implemented e-learning modules for their students. Heniz *et al.* (2010) devised online modules to teach evolution to undergraduate students. They were designed so that students could work at their own pace away from the classroom, and involved enquiry-based activities to promote conceptual change and help challenge misconceptions. They found, through using unannounced pre and post tests, that online learning modules such as theirs could benefit students, especially those who were struggling. Similar positive outcomes were found by Bromham and Oprandi

(2006). Their students showed significant positive correlation between online self assessment activities and formal assessment tests. However, this endorses self assessment tests, rather than online learning as such. Also, these examples are university rather than school based studies.

Many educators have suggested their own ideas for evolution teaching and learning activities. Some of these feature new ways of looking at commonly taught aspects of evolution, such as teaching species (Ellis and Wolf 2009) and human evolution (Alles and Stevenson 2003), whereas others feature uncommon ideas in evolution education, such as regressive evolution (Espinasa and Espinasa 2008). Andrews *et al.* (2011) asked students to decide whether humans are evolving. Through looking at traits such as height, over 75% of students were reported to have changed their initial misconceptions. Other ideas for teaching activities involve simulation, such as Stebbin and Allen's (1975) simple idea to replicate natural selection which involves students (acting as predators) picking different coloured counters (representing prey animals), depending on the colour of the background (indicating the natural environment). Some simulations even involve the physical movement of students, for example, Price (2010) encourages the use of role play where students 'perform' natural selection through a series of movements or gestures. Computer simulations are increasingly recommended, especially at university level. For example, Soderberg and Price (2003) describe a lesson using *EVOLVE*, a computer simulation package to help students use problem-solving to improve their understanding of evolution and population genetics, and Christensen-Dalsgaard and Kannevorff (2008) use the hands-on and computer modelling of *Lego*® to help students investigate adaptation by natural selection. Although there is considerable support for the potential of such computer-based resources in schools, teachers must be careful to address any misunderstandings that could arise, and not get distracted by the fun, student-friendly graphics and gaming approach that some simulations use (Bean *et al.* 2010).

Most of these suggested activities are designed for undergraduate rather than school teaching, therefore the concepts discussed are more complex than would be expected in schools. However, most have the potential to be tailored to secondary

school level and could potentially help motivate and interest students. Unfortunately teachers do not always have access to ideas or the time to modify activities to an appropriate level. Clearly there is a need for a variety of engaging activities which are produced specifically with school students in mind, and differentiated to meet the needs of different abilities.

1.2.4 Teaching genetics

Genetics is another important topic that students might only learn about formally during their secondary school education. Recent advances within genetic fields such as genomics and genetic engineering have vast implications, particularly concerning human health and disease (Williams *et al.* 2012). There are concerns that, due to a lack of understanding of genetics, the public are not prepared for health-related technologies, including genome sequencing and personal genomics, and the potential impact they may have on individuals (Kung and Gelbart 2012). Education that includes up-to-date information and applications is recognised as vital.

Teaching genetics is a relatively neutral subject: genetics is not considered controversial in the ways that evolution might be (with the exception of some of the more recent debates surrounding health, but these are related to applications, rather than gene theory itself). There is research into students' understanding of different genetic-associated ideas, and suggestions of how best to teach the topic. It should also be noted that genetics can be difficult for students to understand, and there are many associated misconceptions which have been well documented (e.g. Moll and Allen 1987, Banet and Ayuso 2000, Duncan and Reiser 2007).

Research implies that students often lack basic understanding of organisms. Misconceptions about plant reproduction, location of inheritance information, and the relationship between chromosomes, genes and alleles are also common (Banet and Ayuso 2000, Lewis and Wood-Robinson 2000), as are confusions of cell division (Williams *et al.* 2012). Traditional teaching of genetics tends to focus on Mendelian genetics and problem solving activities. Banet and Ayuso (2000) suggest that this may not be a good starting point due to students' lack of knowledge and interest in plants. Instead they recommend that human inheritance

is central to any introduction to genetics. Even where students are able to complete activities, such as mathematic problems, this may not show understanding of the topic. Much genetics education tends to be focused on traditional approaches, although genetic engineering and debates around health and disease appear to be increasing in popularity.

1.2.5 Evolution and genetics in the UK

In the UK, most current secondary school students are first introduced to the theory of evolution during their secondary school education. Since the National Curriculum was introduced for schools in England and Wales in 1988, evolution has been a compulsory part of secondary science classes and is currently included in GCSE (General Certificate of Education) science and biology examination courses, typically taught to 14-16 year olds (QCA 2007, Williams 2008).

This situation is changing. Evolution was introduced to the primary curriculum in 2014. This new addition is proving challenging with many primary school teachers, especially non-science specialists, concerned about what to teach and how. This is a current area of much research (e.g. Buchan 2015, Russell and McGuigan 2015). It will be very interesting to see if and how this earlier introduction impacts students as they progress onto secondary school and beyond.

The current GCSE structure is also undergoing much change with new syllabi appearing regularly (much to the distain of overworked teachers). The majority of the current (2012-2015) secondary school biology courses contain separate modules or topics featuring evolution and genetics. Most of these do not specifically link evolution and genetics, despite the obvious relationship between the two. According to exam board specifications and many secondary school textbooks, evolution is always supported by fossil evidence, but there is rarely any mention of genetics. Although both genetics and evolution will be taught to secondary school-aged students, the order of these topics depends on exam boards and school or teacher preference. Further information related to the National Curriculum and exam board specifications can be found in the supplementary materials.

1.2.6 Limitations and conclusions

Given the importance of evolution within biology, there is relatively little work which focuses on improving the teaching and understanding of evolution. As noted by Donnelly *et al.* (2009), much of the current evolution education research is based on university students and may not be applicable to school students. Secondary school level biology is usually compulsory for all students up to the age of 16, whereas university level courses are likely to be taken by more scientifically and academically orientated students, therefore studies related to university students may not be very meaningful for younger learners. Researchers may find it easier and more convenient to study university students, but clearly there is a need for school-specific research into views on teaching, understanding and accepting evolution, teaching strategies and resources. The majority of research is based in America, where academic stages and curricular are different from those in the UK. Although inferences can be made from such studies, the social and political context may be very different between different countries.

Sample sizes and subjectivity of the samples could be questioned for some voluntary, survey-based studies. For example Zimmerman (1987) received responses from just 29% of schools which questionnaires were sent to, 48% of teachers replied to Shankar and Skoog's survey (1993) and Donnelly *et al.* (2009) received consent forms from 33% of students. Those teachers or students which complete surveys may be the more diligent, or those with the strongest view points, and results may therefore be biased (Alters and Nelson 2002, Bowman 2008). Due to the sensitive nature of some of the aspects of the studies, such as religion and beliefs, participants may feel uncomfortable and give the answers that they think are expected of them or that the researchers want to hear, rather than answering honestly (Deniz *et al.* 2008).

Most journal articles are written by academics. Some research into the teaching of evolution is directed at university level students and, although many such studies are potentially useful in school classrooms, most suggested activities are at too high an academic level. Even those articles that do focus on schools may include inappropriate or unrealistic teaching activities, require resources which are not readily available in schools, or be too complex for the majority of secondary

school students. For example, Fail (2007) suggests that teachers place large maps on classroom floors which students can then crawl over to locate areas that are important to evolution, such as the Galapagos. Not only does this seem a rather inappropriate activity for secondary school-aged students, but it appears very unlikely that science laboratories, many with stationary work benches, will have the space for maps big enough for up to 30 students to crawl around on. Although much of the advice given by may be good, researchers do not always appear to understand the time constraints placed on teachers and lessons. Activities need to be tested and evaluated by school teachers and students if they are to be effective for classroom use.

It is important for school students to gain a good basic understanding of evolution and genetics, whether that be as a basis for their future studies, or in readiness for potential interactions with these topics in their personal lives. It is clear that further research into effective evolution education is needed which is based on school studies and has input from teachers. The need for up to date, accessible teaching resources and better training of teachers is highlighted by a number of studies (Linhart 1997, Griffith and Brem 2004, Moore 2004). It should be remembered that, although popular opinion may try to determine what is taught in school, it does not make sense for this to happen (Zimmerman 1987). Controversies cannot be ignored, but their inclusion in science lessons should not be to the detriment of intellectual content. Research is currently lacking in many areas. Education policy makers need to recognise evolution as a central theory in biology and allow for a school curriculum which reflects its importance.

Chapter 2. Methodology

Here I discuss the rationale behind approaches used to data collection and the research instruments used within this study. A student questionnaire has been developed to determine acceptance of evolution and understanding of evolution and genetics. This has been informed by extant research instruments but has been devised specifically for secondary school-aged students. This has been piloted with secondary school students and found to be appropriate for this academic stage. A focus group structure has been established to uncover further information about students' views and understanding of evolution. A teacher survey has also been established, based principally on existing research instruments.

This chapter describes the approaches chosen for data collection, the development of research instruments, the challenges of engaging educators with the research project, and provides information on sample sizes and compositions. A mixed method approach has been utilised to answer the research questions and has involved both quantitative and qualitative methods. Mixing methods has become common in social and education research, particularly in applied research, due to the often complex and multi-dimensional aspects of subjects being studied (Ritchie and Ormston, 2014).

Quantitative methods typically involve the collection of measurable, usually numerical data. Findings are often generalised to the wider population and results should be replicable. Qualitative approaches tend to be associated with social sciences and produce data related to particular individuals or groups of individuals. It is not always possible to generalise or replicate these data. They offer more flexibility than quantitative methods, which are pre determined by their research instruments. Qualitative methods are heavily influenced by the researcher at all times whereas quantitative methods are less influenced by the researcher, following the initial design of the research instrument. It is hoped that by using mixed methods, it will be possible to exploit the strengths of both quantitative and qualitative methods and gain better understanding of the research subject (Miles *et al.* 2014, Ormston *et al.* 2014).

Within this study, most data are quantitative and have been generated through the student questionnaire. Qualitative research has primarily been used to further investigate issues raised from these data, with students. Teacher interviews have also been used to inform the development of research instruments, and to analyse their use. Teacher surveys have provided predominantly quantitative data, but comment boxes have also been used to gain further qualitative information.

The vast majority of data, analyses and interpretations have come from the student questionnaire, and so much of this chapter and forthcoming chapters are dedicated to this research instrument. Data were also collected from student focus groups, teacher interviews, and teacher and pre-service teacher surveys. The designs of these are outlined within this chapter. Details of how schools and teachers were recruited for involvement in the project are discussed and ethical issues are considered.

2.1 Student questionnaire

Quantitative data were collected through a student questionnaire to determine acceptance of evolution and understanding of genetics and evolution. This was devised for GCSE level students (14-16 year olds) who study evolution and genetics as part of their science GCSE science course. This academic stage was chosen as it is currently the first, and perhaps only, period at which students have to learn about evolution (this has changed since the beginning for the study – see section 1.2.5 for further information on the introduction of evolution to the primary curriculum). This cohort is not self-selecting in the way that a higher academic stage might be. For example, students aged between 16-18 and studying for a Biology A Level qualification will already have achieved a reasonable standard of academic achievement in science to enrol onto this, and presumably have interest for biology, or would not have chosen to study the subject further. Therefore, in choosing to study GCSE level students, this research will involve a wide variety of students, in terms of academic ability and interest in evolution and science.

Where possible, the student questionnaire was used at three times:

- Pre test – prior to learning both genetics and evolution;
- Post test – immediately after learning of both topics;
- Retention test – approximately three to six months after the teaching of the topics (but not coinciding with any revision or examination of topics).

This study utilises a randomised control trial method. Most schools continued to teach these topics as normal, with existing variation, such as topic order, being comparative between classes without further intervention. However, some schools were also asked to make changes to their normal teaching, such as to change the order in which evolution and genetics were taught, and/or to include an activity which linked the two topics. Due to the time constraints of teaching exam specifications and limited flexibility within some school schemes of work, there was no pressure placed on teachers to change their normal teaching sequence or include different resources.

The questionnaire consists of 26 questions: 14 focus on acceptance of evolution (Section A), six on genetics knowledge (Section B) and six on evolution knowledge (Section C). None of the questions involve extended writing and are all variations of the multiple choice question. These types of questions were chosen for their practicalities: to aid student completion time, to avoid instances of not being able to understand transcriptions, to allow for quantitative analysis of data, and as this method is commonly used in similar studies (e.g. Rutledge and Warden 2000).

At all stages of the questionnaire development, evolution and education experts were consulted from the University of Bath along with practising teachers. The questionnaire was designed with time constraints in mind: teachers consulted during its development were insistent that the questionnaire must be short enough so that its completion would not considerably reduce their lesson time. 10 to 15 minutes was considered an appropriate length. The full student questionnaire can be found in Appendix A.

2.1.1 Evolution acceptance

Section A assesses students' opinions towards evolution and consists of 14 Likert Scale items. These statements relate to different aspects of evolution, including the evolution of man and the evidence for evolution, as shown in Figure 2.1. These were based largely on the Measure of Acceptance of the Theory of Evolution (MATE), which was developed to assess biology teachers' acceptance of evolution (Rutledge and Warden 1999) and later, undergraduate students' acceptance of evolution (Rutledge and Sadler 2007). The original MATE instrument consists of 20 items spread disproportionately across six subsections of evolutionary concepts or aspects. It was decided that this was too long for school students. Appropriate questions were chosen based on their relevance to these different aspects of evolution and their accessibility to school-aged students. Given that the MATE has been developed and tested predominately on teachers and undergraduate students (e.g. Rutledge and Warden 2000, Rutledge and Sadler 2011), some modifications to the language used were needed. Where necessary, statements were reworded to make them more understandable. In addition, two items (questions 7 and 13) include ideas on humans and dinosaurs used by Lovely and Kondrick (2008) to assess undergraduate students' acceptance of evolution.

| Aspect of evolution | Item (agree) | Item (disagree) |
|---|--------------|-----------------|
| Evolution as an explanation for modern life | 1 | 8 |
| Human evolution | 3 | 12 |
| Evidence for evolution | 4 | 2 |
| Scientific community's view of evolution | 5 | 11 |
| Scientific validity of evolutionary theory | 10 | 6 |
| Dinosaurs and humans | 13 | 7 |
| Geological time | 14 | 9 |

Table 2.1 Aspects of evolution tested within the evolution acceptance section of the student question. 'Agree' and 'disagree' refer to the response that would be expected from a student who is accepting of evolution.

Each aspect of evolution is presented twice, but in reverse, as shown in Figure 2.1. Questions 3 and 12 both ask for students' views on human evolution: question 3 is positively worded towards an evolution-accepting response whereas question 12 would require a negative response from the same student, if they understand the questions. This is common practice in questionnaire design and allows for assessment of internal consistency. Negatively worded items are reversed scored and all responses are then summed to give an overall score. Scores for individual questions are measured on a scale of one to five, giving a total score between 14 and 70 (a higher score represents a higher acceptance of evolution).

| | | | | |
|---|-------|-----------|----------|-------------------|
| 3. Modern humans are the product of evolutionary processes that have occurred over millions of years. | | | | |
| Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
| ----- | | | | |
| 12. Humans exist today in the same form in which they always have. | | | | |
| Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |

Figure 2.1 Examples of questions used to assess students' acceptance of evolution in the student questionnaire.

2.1.2 Genetics knowledge

Section B consists of six questions which focus on knowledge of genetics. This includes variations on questions from recent GCSE exams, questionnaires used in the Genetics Literacy Assessment Instrument (GLAI) for undergraduates (Bowling *et al.* 2008) and questions from Lewis and Wood-Robinson (2000) in their study of school students' understanding of genetics. Two of these questions involve choosing or ordering key words from lists provided, and one question

involves ticking boxes. These types of questions were chosen to gain greater insight into students' ideas on living organisms and genetics and to add variety to the questionnaire for students.

Selecting suitable questions to encompass the wide potential span of 'genetics' and which could be completed within a limited time span proved challenging. Rationale behind deciding which aspects of genetics should be covered (or not) included whether these aspects were covered by the majority of GCSE syllabi. For example, although cell division appears in the literature as a topic that causes confusion (and interviews with teachers confirmed this was a key concern in project schools), this was not included in the student questionnaire because coverage of this varies between exam boards and ability tiers. Instead, a number of questions focused on more basic knowledge of cells and terminology. Question 15 assesses students' understanding of 'size sequence', question 16 gauges awareness of 'living things' (both after Lewis and Wood-Robinson, 2000), and question 17 questions knowledge of 'biological terms' (based on typical key words used in exam specifications and used in examinations). The remaining three questions within this section are more commonly used multiple choice-type questions, and involve choosing one response from a possible four answers. These questions include a mixture of exam-type questions and test common misconceptions with distractors' as possible answers. Not all of the six questions were scored equally: questions 16 and 17 awarded marks for each correct answer given, meaning an overall maximum score of 34 for this section of the questionnaire.

2.1.3 Evolution knowledge

Section C focuses on evolution knowledge and consists of six questions. Question selection was again challenging, especially given mixed coverage of evolution between exam boards. This section includes a variety of different aspects of evolution, including natural selection and geological time. Most of these were variations of questions used by Rutledge and Warden in their 2000 research into acceptance and understanding of evolution among high school biology teachers. Additionally, a number of questions were devised with the assistance of evolution experts. Each question was scored equally with a section total out of six.

All questions were multiple choice with four possible answers. Again, distractors were used to highlight common misconceptions. For example, in question 21 (shown in Figure 2.2), answer C represents Lamarckian thinking. It is accepted that for some of these questions, multiple answers could be considered correct on a micro-evolutionary or epigenetic scale, however this type of response is deemed highly unlikely given the academic level of the students completing the questionnaire.

21. Which of the following phrases best describes evolution?
- A. The development of man from monkey-like ancestors.
 - B. The change of simple to complex organisms.
 - C. The development of characteristics in response to need.
 - D. Genetic changes in populations through time.

Figure 2.2 Example of a question used to assess student understanding of evolution.

2.1.4 Pilot study

The original questionnaire consisted of 24 questions and can be found in the supplementary materials. This was piloted during July 2012 with 24 Year 10 (14-15 year-old) students from a high ability set who were visiting the University of Bath to complete practical lab work related to their GCSE course. The purpose of the pilot study was to test the suitability of questions and the time taken by students to complete the test, rather than to investigate any relationships between evolution acceptance and understanding, and genetics understanding. All students completed the questionnaire anonymously and no personal data were collected on any students.

All students completed the questionnaire within 15 minutes, and many in under 10 minutes. Most students appeared to have no difficulty in responding to questions: there only were five incidents of non-response items. Internal consistency was used to measure the reliability of evolution acceptance questions. This is based on correlations between responses and provides a score between 0 and 1 (Oppenheim 1992). The reliability scores for evolution acceptance were 0.69 (Cronbach's alpha) and 0.87 (Guttman's Lambda 6). These are acceptable and suggest the

questionnaire is reliable. (Internal consistency will be discussed further in Chapter 3 and further details of the analysis of the pilot question can be found in the supplementary materials.)

Given that the students involved in the pilot study were from a high ability set and had covered these topics, it was expected that most students should be able to answer the majority of questions successfully. However, a key component of the questionnaire is its sensitivity to detect small changes in understanding, therefore it was meant to be challenging. Scores ranged from four to 12, out of a possible total of 12, with the mean being eight. The results show that able students with good subject knowledge are able to score top marks on the questionnaire, but that it is not so simple that all students will achieve highly. The questionnaire therefore does ask questions of an appropriate knowledge level; however this way of scoring questions, particularly where individual questions were multifaceted, may not be the most efficient way of understanding student responses. The frequency of correct answers is shown in Figure 2.3.

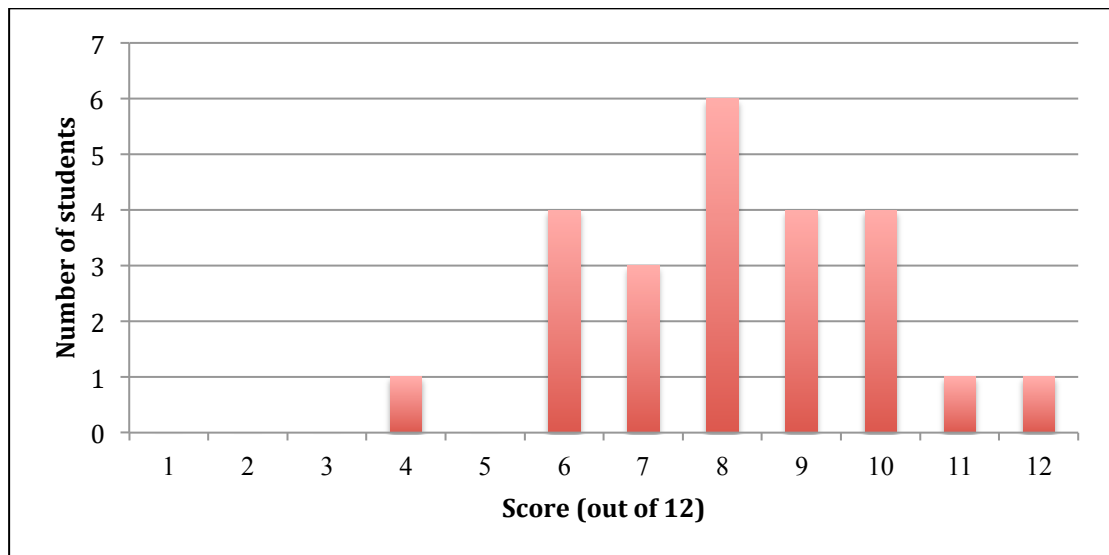


Figure 2.3. Correct answers for knowledge questions (sections B and C) in the pilot study (N=24). Each question was given the same weighting; where questions involved more than one correct answer, e.g. question 15, a score was given based on the proportion of correct answers and then rounded to the nearest whole number.

Students were also requested to give feedback on the questionnaire. Participants were asked for their opinion as to how easy it was to understand and answer the questions, whether they found the questions interesting, and their views on the length of the questionnaire. Answers were given on a scale of one to five but there was also opportunity for individual written responses. Given the anonymous nature of this activity, it is assumed that students were honest in their responses. Student feedback of the questionnaire is displayed in Figure 2.4. Class teachers present during the pilot study, including a Head of Science, were also asked for their feedback of the questionnaire. All the teachers responded positively and were keen to use questions from the questionnaire during their teaching and assessment.

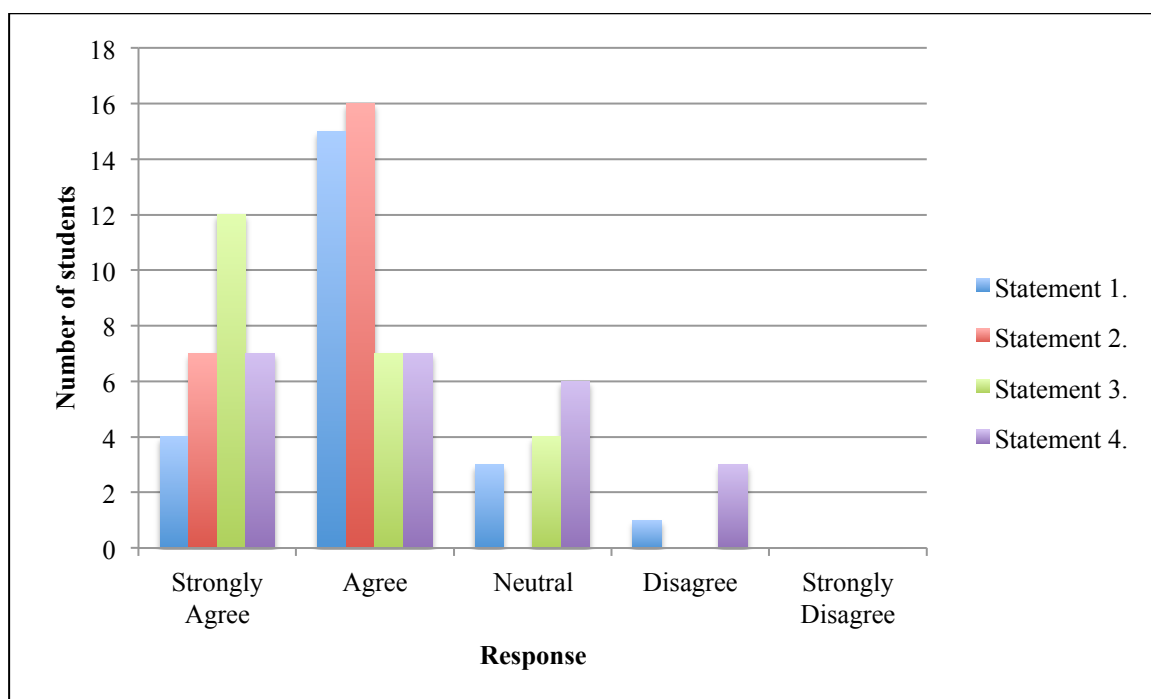


Figure 2.4 Responses to the feedback statements in the pilot study (N = 23 [one student did not respond to any of the feedback questions and has been omitted from these results]). Statement 1: "It was easy to understand what the questions were asking"; statement 2: "It was easy to answer the questions"; statement 3: "The questions were interesting"; statement 4: "The questionnaire was about the right length".

The focus of the pilot study was not to assess acceptance or knowledge of students, but to test whether the questionnaire was accessible and appropriate for students of GCSE age, and whether the questionnaire could be completed within a

time limit suitable for teachers. Overall, findings from the pilot study suggest that the questionnaire is suitable for able GCSE school students and, given that all students completed the questionnaire within 15 minutes, the length of the questionnaire is within what teachers consider to be an acceptable amount of time. The pilot questionnaire received positive feedback from students. The majority understood what the questions were asking and did not seem to find the questionnaire too long or uninteresting.

2.1.5 Development of the questionnaire

All questions were critically examined in light of the pilot study, particularly those where there were lower numbers of students achieving the correct answer (although given knowledge questions were designed to discriminate between students, achieving variation within these sections was important). Based on this, a number of changes were made to the questionnaire, including the rewording of some questions to improve understanding. Given the time students took to complete the questionnaire, and to increase the number of evolution aspects covered, two additional questions were added to the evolution acceptance section.

There was one instance of disagreement between teachers and academics. Question 21 in the pilot study, which questions the ‘evolutionary success’ of individual birds, was popular among teachers but scientists questioned the correctness of the ‘right’ answer, given knowledge of reproductive strategies (Figure 2.5). Although this level of understanding is unlikely to be problematic in secondary schools, generally the view of the academics was taken over that of the science teachers regarding ‘scientifically correct’ answers, whereas teachers’ views were imperative with regards to pedagogical considerations and practicalities of administering the questionnaire.

21. Which of these birds would be considered the most evolutionally successful?
- A. A bird that lives for 5 years, lays 12 eggs in its lifetime, of which 5 hatch.
 - B. A bird that lives for 2 years, lays 8 eggs in its lifetime, of which 4 hatch.
 - C. A bird that lives for 6 years, lays 2 eggs in its lifetime, of which 2 hatch.
 - D. A bird that lives for 4 years, lays 7 eggs in its lifetime, of which 6 hatch.

Figure 2.5 Question 21 in the pilot questionnaire (after Rutledge and Warden 2000). This question was popular with science teachers but questioned by evolutionary scientists. The ‘correct’ answer is D but this does allow for different reproductive strategies.

Alterations were made to the scoring of items following the pilot. It was decided that each part of the six questions did add value to understanding students’ knowledge of genetics, therefore each section of a question which could gain a mark, did so. This also acknowledged the effort needed to complete questions 16 and 17, compared to the other questions. The genetics section is now scored out of 34.

There are often issues concerning the order of questions and answers, with answers higher up in a list typically being chosen above later answers, and non-response items being more common later in a questionnaire (Cohen *et al.* 2011). Although the pilot study did not suggest there may be any issues, there were concerns as to whether there may be higher incidences of non-response towards the end of the questionnaire. Also, if time was short, and/or if students were taking too long, whether the last page (evolution knowledge) might suffer. However it was decided to keep the sections and questions in the same order: section orders were not changed, nor were individual question orders changed. Evolution acceptance and genetics knowledge were (originally) deemed most important, and this is also reflected by the number of questions in each section. Also, we did not want to introduce further variables, especially when, although aiming for large sample size, this was not guaranteed. It was not possible to test different orders of topics during the pilot as we did not have the time or sample size for meaningful comparisons.

The questionnaire was piloted with high ability students and no students appeared to struggle with reading or understanding the questionnaire. Readability tests were also used in an attempt to simplify wording, however the scientific nature of the language needed meant that some parts of the questionnaire were quite difficult (see Table 2.2). It was anticipated that lower ability students or those whose first language was not English, might struggle with the wording of the questionnaire. After discussing this with teachers, a strategy to help overcome this was implemented. Teachers of lower ability classes or those that were concerned about the difficulty of the questionnaire were instructed to read the questionnaire out loud to their class (with or without the assistance of a PowerPoint version of the questionnaire) and help their students with the understanding of the questions. They were not, however, allowed to assist students with the scientific concepts or give the students answers. In addition to this, teaching or language support assistants were able to support students as they might do in normal lessons.

| Section | Flesch reading ease (%) | Meaning | Flesch-Kincaid grade level | Approx. UK equivalent age |
|--------------------------------|--------------------------------|------------------|-----------------------------------|----------------------------------|
| Evolution Acceptance | 35.6 | Difficult | 11.3 | 16 |
| Genetics understanding | 54.3 | Fairly difficult | 6.9 | 12 |
| Evolution understanding | 39.1 | Difficult | 9.4 | 14 |

Table 2.2 Readability of the different sections of the student questionnaire. These were calculated using Microsoft Word based on the principles of Flesch. Variation has been reported between readability assessment methods and the limited use of such tests, therefore, although a useful guide, these scores are not considered in isolation to other factors within the context of the student questionnaire. Full details can be found in the supplementary materials.

Unlike the pilot study, student name sheets were attached to questionnaires used for the main study. These were necessary for longitudinal paired comparisons. However, it was clearly stated the reasons why names were needed, and that responses would remain confidential. Teachers were provided with guidance sheets which explained how to use the surveys, and, again, why student names were needed. Despite this, a number of students did not give their names, or used

fake names (this was not problematic where students used the same name in pre and post surveys, but anonymous questionnaires were slightly more problematic. This is discussed further in Chapter 10). Students were not asked to provide any further personal information (such as gender or faith). This was to help reduce time spent on the questionnaire, to reduce student concerns about the purpose the study, and as these are not key research questions. Details of the administrative process behind questionnaire organisation and distribution, and all the documents mentioned above, can be found in the supplementary materials.

All student questionnaires (with the exception of the pilot study which took place within a teaching lab at the University of Bath) were completed during students' normal science lessons, as part of their evolution and genetics lessons. No researchers from the University were present during the completion of the questionnaire (or during the teaching of evolution and genetics in classrooms. Although lesson observations were considered as a research strategy, the impact of having additional people in the classroom, and the time constraints of visiting schools at the correct time of teaching, raised too many questions over the ability of this method to provide meaningful data with respect to the research questions, thus observations did not take place as a means of data collection). All schools were provided with 'opt out' permission forms for their students. Very few schools thought these were necessary as they viewed the questionnaire as part of their normal science class, however this responsibility was left with Heads of Departments. Nonetheless, students were free to withdraw from the study at any time and were under no pressure to answer any questions.

2.1.6 Recruitment of schools

Making contact with schools and enthusing teachers has been an important part of the project. Schools were given incentives to participate, including potential benefits for current and future students, free resources, strong links with the University of Bath, visits to the University, professional development opportunities for teachers, and the potential for supply teachers or other associated costs to be covered by the project. Despite these benefits, recruitment of schools to the project proved extremely challenging.

During the first year of research, teachers were contacted in person through university conferences and STEM days, and by email through STEM co-ordinators, links within the University, such as through the Widening Participation and Alumni Offices, and also through personal links to teachers. During the second year, secondary schools within the Bath, Bristol and North Somerset areas were written to, inviting them to participate in the project. During the third year of research, all schools in the south of England and in South and Mid Wales that offered a GCSE or GCSE level equivalent curriculum were emailed. In addition to these direct methods of contact, the project has been advertised on the TES website ([http://www.tes.co.uk/MyPublicProfile.aspx?uc=2475830 &event=21](http://www.tes.co.uk/MyPublicProfile.aspx?uc=2475830&event=21)) and through Twitter (<http://www.twitter.com/GEVOteach>). A project website has also been developed to provide information on the project and allow interested schools to easily make contact (<http://go.bath.ac.uk/GEVOteach>). Examples of letters and emails to schools can be found in the supplementary materials.

Of approximately 750 schools in the South of England and South and Mid Wales contacted directly through letter and/or email, positive responses were received from over 50 schools, representing a response rate of less than 10%. Unfortunately there were issues with lack of response to emails and for teachers to find time for meetings. Questionnaires were distributed to 40 of these schools. Not all of these schools returned the questionnaires, and many schools did not return as many sets of the questionnaire as had been previously discussed and printed. Despite this, a large number of questionnaires were returned.

2.1.7 Data overview

Table 2.3 gives an overview of responses collected from the student questionnaire. These were collected from a total of 78 classes within 23 different schools between September 2012 and September 2015. In total, 1886 students completed the questionnaire at least once. Table 2.4 shows the numbers of students associated with key variables to be investigated, namely ability and topic order. Detailed information on numbers of responses and other variables can be found in the supplementary materials. Although 3572 questionnaires have been received in total, there is a large amount of variation in the number of pre, post

and retention tests completed, as can be seen in Figure 2.3. Individual students have been omitted from certain analyses, e.g. those comparing pre and post, where students were absent at the time one of these questionnaires was completed. Data have been used where possible as there is still value in students' responses at a single point in time, even if it has not been possible to compare paired data longitudinally. Sample sizes therefore differ considerably for different analyses.

| | Pre | Post | Retention |
|---------------------------|------------|-------------|------------------|
| Number of students | 1716 | 1527 | 329 |
| Number of classes | 76 | 72 | 18 |
| Number of schools | 23 | 23 | 8 |

Table 2.3 Overview of student questionnaire data collected.

| Variables | Sub sample | Number of students | Number of classes |
|--------------------|------------------------|---------------------------|--------------------------|
| Ability | Higher | 1456 | 56 |
| | Lower | 430 | 22 |
| Topic order | Genetics first | 1145 | 49 |
| | Evolution first | 741 | 29 |

Table 2.4 Sample sizes for variables of key interest.

Unfortunately, six additional sets of questionnaires were received between late December 2015 and January 2016, after the majority of analysis had already taken place. It was too late for these to be included in this thesis, but it is hoped that these data may be used as part of continued work.

I put all data from the student questionnaire into spreadsheets. There were a number of issues where questionnaires were not answered in the predicted way, or where students gave ambiguous answers. Consistent recording of these was adhered to. This shall be discussed further in Chapters 3 and 10.

2.1.8 Background information

A mixture of state, faith, and independent schools have been involved in this project. All schools are from the South of England and Mid and South Wales. All are English language schools. Schools included students from socially and economically diverse communities, including rural, suburban, and inner city. A number of schools are single-sex. Although data were not collected specifically on student demographics, a wide range of ethnic backgrounds and faiths were represented. Background data on schools have been collected from inspection (OFSTED/ESTYN) reports, school websites and from meetings with teachers. This can be found in the supplementary materials.

2.2 Focus groups

A small number of students were involved in focus groups to gain qualitative data. These were designed to better understand the responses found in the student questionnaires. The specific aim of the focus groups was to gain understanding of why students had given the responses in the questionnaires, i.e. why students were or were not accepting of evolution; how these views related to knowledge of evolution; how these related to knowledge of genetics; and what other factors are important.

2.2.1 Question development

The flexible nature of focus groups allows for deviance from a rigid questioning structure. A question sheet was devised as guidance, but not all questions were used with every group. This can be found in Appendix B. Although some questions were aimed at individuals, and those responses were of huge value, the interactions between individuals was also important, especially where focus groups contained a variety of opinions and experiences of evolution education. The synergetic nature of focus groups allowed for each discussion group to vary based on the responses of the students involved.

The design of the focus group was informed by questionnaire findings and more specific aims and questions were developed as data from more questionnaires were collated. For example, it was obvious from questionnaire responses that

students already knew of evolution, even if this deviated from scientific knowledge, and many students had an opinion on the topic, prior to education. Therefore, trying to ascertain when and where students might have first heard of evolution, and places other than school that they may have learnt about evolution from, was an interesting way of introducing the topic prior to asking students key questions related to their acceptance and knowledge of evolution.

The focus group also provided a way of asking students about their recent GCSE evolution and genetics lessons. Within some schools, this was used as a means of discovering student views on resources developed as part of the GEVOteach project, and can also be used to inform future resources. Questions pertaining to resources were related to preference, e.g. what lessons or activities were particularly memorable or enjoyable, but also questioned the effectiveness of these activities, e.g. whether can students explain the concepts involved.

As with the student questionnaires, expert advice was sort when developing ideas for the focus group. This was particularly valuable in terms of conducting focus groups and working with young students.

2.2.2 Pilot study

A pilot focus group was conducted to trial different questions and discussion group structure. Although pilot focus groups are not always needed for these types of studies, it was deemed sensible to trial whether questions were suitable for secondary-age students, groups of students, and for the time period focus groups were likely to run for.

The pilot study involved two school-aged students and a non-science specialist secondary school teacher. Both students were from different schools: one state (Welsh language) and one independent (in England). The teacher was educated in a state school in South Wales (English language) and had worked in a variety of schools in the South of England and South Wales. One student had not yet learnt about evolution but was very interested in the topic, hence eager to be involved in the focus group. The other student had recently learnt about evolution and genetics in preparation for their imminent GCSE examinations. The teacher did

not remember formally learning about evolution. All three participants were known to the researcher prior to the focus group. The pilot study was not recorded, as the main purpose was not to collect information about the participants views and knowledge, but to practise questioning, confirm questions were suitable, and to ensure that discussion from them would maximise the time available.

The pilot study confirmed that questions were suitable for students aged between 14 and 18 and understandable by students of varying abilities and experience of different schools and evolution education. It was realised that, particularly if group numbers were small or if students were not forthcoming with information, having additional questions, such as the statement on evolution acceptance from the student questionnaire, were a useful way of encouraging more discussion and probing different views on different aspects of acceptance.

2.2.3 Conducting focus groups

All schools that had been involved in the student questionnaire were invited to participate in focus groups. The administrative process of organising focus groups, permission from parents or guardians, and consent from students themselves, required a lot of organisation. Information on this can be found in the supplementary materials.

Permission from parents or guardians was received for all students prior to the focus groups and students completed consent forms before the focus groups began. Students knew in advance that the focus groups were being audio recorded and all students gave consent to this, and to their views being used anonymously for research purposes. (The recordings were later transcribed for analysis.) Students were aware that that they could leave the focus group at any time and that they were under no obligation to answer questions. All students were asked to respect other participants' views and all behaved in an appropriate manner.

All focus groups took place within students' schools, usually within their normal science classroom or lab, or occasionally in meeting rooms or libraries. An adult

from the school, such as a teacher, teaching assistant, or lab technician, remained within sight and earshot of the discussion groups at all time.

2.2.4 Data collection and input

In total, 76 students were involved in 16 focus groups. These students were from 10 different schools. The largest focus groups contained seven students and the smallest, two. All students were from groups identified as “higher ability”, with most students being from among the top sets in each school. However, there were a small number of students who were from middle ability sets. The majority of students were in Years 9, 10, and 11 and studying towards their GCSE examinations. Six students were in Year 12 and studying for A Level exams. Most focus groups comprised students of the same age and from the same class, however there were three groups which contained a mixture of ages and classes. (Full details in the supplementary materials.)

2.3 Teacher interviews

Interviews with teachers occurred at a number of points during the project. These meetings were relatively informal and not recorded, but many notes were taken by hand at the time and written up in a fuller form as soon as possible following the interview. Usually these interviews involved the Head of Science or the teacher most like to lead the project within the school, but sometimes meetings involved a number of teachers and in some schools, science technicians. Interviews followed a pre-determined format and set questions, but as with the student focus groups, there was a lot of flexibility for alternative lines of discussion. An outline of the interview format and questions can be found in the supplementary materials.

Most teachers were visited in school prior to involvement in student questionnaires. The purpose of these meetings was to discuss if and how schools could become involved in the project, but also, particularly in initial meetings, to gain further insight into how different teachers approached evolution and whether there were any ways in which they would like support, such as any particular resources. Where it was not possible to meet teachers in person, phone interviews took place, or in the case of a small number of teachers, discussions were purely

by email. This generally produced less information than speaking in person or over the phone, but still proved important. All interviews that took place in person or via telephone were followed up by email.

A small number of teachers were involved in interviews after the involvement in the project. Due to time constraints and failure to gain all of the information needed about all the classes involved in the first year of data collection, a 'Teacher question sheet' was introduced during the second year of the project. This was to be completed by teachers at the time their class(es) were completing the post questionnaire and asked teachers to confirm details of their class, teaching order of topics, and the types of resources used. (This can be found in the supplementary materials.) This largely replaced the need for follow-up interviews, although these did still take place where possible, often coinciding with student focus groups.

2.4 Teacher surveys

The teacher survey has been developed to gain a better understanding of secondary school teacher and pre-service teacher acceptance of evolution, knowledge of evolution, and knowledge of genetics. It has also been designed to appreciate how teachers can be better supported in their teaching, to gain ideas for resources, and to promote the GEVOteach project.

2.4.1 Design of the teacher survey

The survey is based on the student questionnaire described in section 2.1 for use in secondary schools and also incorporates additional questions from the primary school teacher question (Buchan 2015). The survey can be found in Appendix C. It includes sections on evolution acceptance, genetics knowledge and evolution knowledge but also requires teachers to provide background information on themselves, their confidence in teaching evolution, and suggest ways in which they might appreciate support (if any). The order of sections is different from that found in the student questionnaire with genetics and evolution knowledge section orders being reversed. A table matching comparative questions across the student

questionnaire, teacher survey, and pre-service teacher survey can be found in the supplementary materials.

The full 20 item version of the MATE (Rutledge and Warden, 2000) is used to assess evolution acceptance. This has small alterations to the original MATE. For example, question 9 (question 8 on the pre-service teacher survey), item 15, uses the word ‘religion’ instead of ‘creationism’. This was changed to reflect multiculturalism with the UK, and responses expected (and is in keeping with the student questionnaire). The two additional questions found in the secondary student questionnaire related to humans and dinosaurs (after Lovely and Kondrick 2008) are also included.

The first part of the evolution understanding section is taken from the Conceptual Inventory of Natural Selection (CINS), developed by Anderson *et al.* (2002) to assess undergraduate students’ understanding of natural selection. The second part of this section consists of the six evolution knowledge questions used in the secondary school questionnaire, as described in section 2.2.3, and an additional two questions, again from Rutledge and Warden (2000). Understanding of genetics questions are those used in the student questionnaire, as described in section 2.1.2. There are slight alterations to the layout out of the answers due to the nature of this being a computerised survey while the student questionnaire was completed on paper.

2.4.2 Distribution of the survey

It was decided that the survey should be web rather than paper-based due to the ease of getting the survey to many potential participants quickly, reasonably cheaply, and with less environmental impact. There were also concerns that large numbers of the survey may not be completed and returned, should they be posted to potential participants. This way also allows the option of continued use of the survey in the future.

The survey was initially promoted through the GEVOteach Twitter account where it received many “retweets” including through organisations such as the Association for Science Education (ASE). All secondary schools in the South of

England and in South and Mid Wales were emailed and all individual secondary teachers who had been involved in the project in some way were also invited to participate and forward the link to colleagues. All participants were offered the chance to win a £50 Amazon voucher (for use at www.Amazon.co.uk) as an incentive. All participants were also given the option of requesting a GEVOteach resource package memory stick. All correspondence relating to this can be found in the supplementary materials.

Pre-service teachers were also invited to participate in the survey. These are postgraduate students who are enrolled on a PGCE course at a university. The pre-service teacher survey was exactly the same as the teacher survey except that the background information questions are relevant to trainee teachers rather than those already working in schools. This can be found in Appendix D. This survey was promoted on Twitter and all PGCE course leaders in the UK were contacted by email. Again, a £50 Amazon voucher and teaching resources were used as incentives. The additional aim here was to gain better understanding of the needs of those entering the teaching profession, and also allowed for comparisons with practising teachers.

2.4.3 Data collection

123 teacher responses and 50 pre-service secondary science teacher responses were collected between March and November 2015. Background information on respondents can be found in the supplementary materials for Chapter 8.

2.5 Data analysis

Two approaches were taken to reporting quantitative findings from this research. The frequency of scientifically correct answers has been the main focus for the majority of comparisons, for example, to compare before and after teaching, and to investigate different variables, such as ability levels. However, the importance of the ideas and understandings or misconceptions which students held is also recognised. These more descriptive findings are utilised in Chapters 4 and 6.

2.5.1 Key variables

There are many ways in which students involved in this project can be separated into sub samples for comparison, and at different levels. These include student factors such as background demographics and socioeconomic factors, class factors which are likely to be dependent on teacher factors, such as knowledge content and teaching experience, and also on school factors, including exam syllabus followed, and the type of school (e.g. state, independent, faith, single sex, etc.). None of these variables have been controlled for and many are likely to overlap and impact on other variables. Given the fluctuating nature of some of these, such as exam board specifications, and due to the specific research questions posed, analysis is focused on the impact of teaching (comparisons of before and after questionnaires), student ability, and topic order. Note that with a large enough sample size, the randomized control structure of the test should ensure that no given variable should bias results.

2.5.1.1 Academic ability

Academic ability is used as a crude estimate of intelligence, which in itself is highly debated and complex to define. Ability is based on the setting of classes. All except one of the schools involved in this research set their classes. Although details of how classes are banded are not known, this is commonly based on test results (both internal exams and external tests including SATs, etc.). For the purposes of this study, classes have been classified as:

- Higher – those studying for GCSE science exams within a class where most students will be sitting higher tier;
- Lower – those studying for GCSE science exams within a class where most students will be sitting lower tier.

In reality, there is likely to be variation within classes. As more data about class ability were collected, students were separated into three groups: higher, middle and lower. These data follow a similar trend to those from higher and lower classes and as may be expected, tended to fit between higher and lower results. However, these boundaries were less clear and possibly less meaningful for an exam system which has only two ability tiers. This approach also resulted in

lower sample sizes for each grouping. For simplicity, only data split into ‘higher’ and ‘lower’ ability students are included here. It should be highlighted that, although students are referred to as ‘higher’ or ‘lower’ ability throughout this thesis, these descriptions are used as shorthand to mean that these students are within higher or lower ability classes. Findings from the three ability groupings can be found in the supplementary materials.

2.5.1.2 Topic order

Topic order is simply categorised as:

- Evolution first (then genetics);
- Genetics first (then evolution).

The schools within this study already taught genetics and evolution in different orders. Most schools simply continued to teach these topics in the order they would normally, but where feasible, schools with more than one class involved in the research were asked to change the teaching order for one class (or more, where greater than three classes were involved).

There are other variables to consider, such as the time between topics. Most were taught one after the other, but for four schools (typically those teaching OCR specifications), there was a considerable amount of time between the teaching of these topics. This is not included in the main results of this thesis, but is discussed further in the supplementary materials for Chapter 5.

To a lesser extent, the impact of resources and links between topics were also considered, for example, were links made between evolution and genetics? If so, what sort of links? Were any particular resources used? These are discussed in Chapter 9. In addition, some analysis of other variables are considered in the supplementary materials for Chapter 5.

2.6 Ethical considerations and data protection

Ethical issues have been considered at every stage of research design and data collection. Ethical guidelines as prescribed by organisations such as The British Educational Research Association (BERA 2011) have been followed. Particular consideration has been taken when working with school students and approaches that place any undue burden on participants have been avoided. Research through questionnaires and focus groups has taken place within students' schools and have involved students' usual science teachers, so as to minimise undue intrusion. School research experts and teachers have been consulted regularly and have informed the ways in which research has been conducted. All relevant forms mentioned within this section and additional information can be found in the supplementary materials.

2.6.1 Student questionnaires

Consent forms for the student questionnaire have been produced. They consist of information for parents or guardians and are to be completed and returned to class teachers if students are not permitted to be involved in the research project. These are shown and discussed with teachers at initial meetings. The majority of teachers, in agreement with their Head of Department and/or Head Teacher, did not use these forms as they felt the questionnaires were part of their students' regular science education, and as they took place in usual lesson time, consent was not needed. However, students were made aware that it was their choice to complete the questionnaire and were able to withdraw from the study should they wish.

Student names were asked for on the student questionnaire. This is to enable later comparisons and once questionnaires are received from all time points, a code is generated for each student and the cover sheet containing student information removed. This was explained to students but some classes used pseudonyms nonetheless. Student names are never entered into computers. All student questionnaires have been kept securely. The Data Protection Act 1998 has been adhered to and no sensitive personal data have been collected. All computerised information regarding schools is password protected.

2.6.2 Student focus groups

Particular care was taken regarding permission and consent for participation in the student focus groups. Teachers were provided with information about what the focus groups would involve and were tasked with selecting suitable students (who themselves had to be willing to participate) and arranging an appropriate venue and supervision for the focus group. Students who were willing to participate were provided with permission forms. These contained information about the purpose of the research project, the format of the focus group, and confidentiality. If permission was given, these forms had to be signed and returned to the students' teacher, before the day of the focus group.

Immediately before each focus group, the format of the session was discussed with students. The use of a dictaphone and confidentiality were discussed, and students were asked to respect the views of other participants. Students were informed that they were free to leave the group at any point and that they did not have to answer any questions. Students also had the opportunity to ask any questions and were given project information sheets to keep, should they later wish to contact the researchers. Students then completed consent forms prior to the focus group commencing. An adult from the students' school was present throughout every focus group.

All permission and consent forms have been kept securely and no personal information has been computerised (students are identified by codes). Recordings of focus groups have been password protected. An external transcription company was used to transcribe recordings. Transcriptionists had signed legally binding confidentiality agreements and all audio files and transcripts held by the company were deleted after they had been delivered.

2.6.3 Teacher surveys

The first page of the teacher and pre-service teacher surveys informs potential participants of the nature and purpose of the research and confidentiality. Consent is assumed to have been given as the participants have actively chosen to complete the survey. Although teachers were asked to give some background information, such as the type of school they worked in and their religion, this was

answered anonymously. Name and contact details were only recorded if the respondent wanted to receive free resources, if they wanted to be entered into the prize draw to win Amazon vouchers, or if they wanted to receive information on the project. Names and contact details were never matched to responses to the other sections of the survey. All personal information is kept securely in password protected files and data protection adhered to.

2.7 Summary

Two quantitative research instruments have been developed to assess acceptance of evolution, understanding of evolution, and understanding of genetics: one for use by secondary school students; the other for science teachers and pre-service teachers. These have been informed by extant research instruments and modified, where necessary, for use with school students. A focus group structure has been developed to further probe student acceptance and understanding of evolution. Pilot studies suggest that that these student instruments are suitable for their intended use. Data collection has proved challenging, but data from a large cohort has nonetheless been gathered. Ethics and data protection are important given the nature of this research project, and have been give full consideration.

Chapter 3. Analysis of the student questionnaire

The student questionnaire has been analysed and found to be reliable for secondary school students. Individual items have been evaluated and provide a range of difficulties levels which assists in differentiating between student understanding of genetics and evolution. Following consideration of all aspects of the questionnaire, the decision was made to remove one item (question 6), due to its poor impact on internal consistency and low validity. All other items remain. Input error has been calculated as 0.09% and is not considered important within questionnaire analyses.

The student questionnaire is the main research instrument used within this study. In Chapter 2, the development of the questionnaire and the rationale behind its design was discussed. Here, the suitability of this research instrument for its purpose is tested, given all the data collected throughout the project. This is an important consideration, especially as most of the research instruments this questionnaire were derived from were not developed for use with the age group included in this project.

This chapter begins by examining the reliability of the student questionnaire. This focuses on evolution acceptance, but knowledge-based questions are also considered. Next, item non-response and item difficulty are assessed. Following this, the validity of the questionnaire is considered. Taking these analyses into consideration, the reasons for the deletion of an item which did not perform well enough is outlined, and potential ways of dealing with issues such as non-response are discussed. Although not directly related to the performance of the questionnaire, input error is also reviewed.

Throughout this chapter and unless otherwise stated, all data are reported (i.e. a combination of all pre, post and retention data). In doing so, it is accepted that intrinsic bias may have been introduced as there is non-independence between data sets. We are aware of this potential issue and the breakdown of questionnaire analyses at different time points can be found in the supplementary materials.

3.1 Reliability

Reliability analysis is used to measure the internal consistency of a questionnaire. It is typically applied in social science research where questions are related to attitudes or opinions and use Likert-type scales (Gliem and Gliem 2003). Most internal consistency measures are based on correlations between responses and provide a score between 0 (indicating no reliability) and 1 (indicating perfect reliability). Interpretation varies but a score above 0.6 is usually deemed acceptable, above 0.7 is preferential, and scores above 0.8 are widely accepted as good (Oppenheim 1992, Cortina 1993, Field *et al.* 2012).

Internal consistency was measured using two frequently reported measures of reliability: Cronbach's alpha (herein referred to as 'alpha') and Guttman's lambda 6 ('G6') (Guttman, 1945, Cronbach 1951). Alpha is most commonly used but has received some criticism (e.g. Cortina 1993, Schmitt 1996, Sijtsma 2009) so for robustness, both measures have been used. Standardised alpha, which is based on correlations, is reported, rather than raw alpha which is based on covariances, as this is the more appropriate alpha for these data (Falk and Savalei 2011).

3.1.1 Evolution acceptance

Reliability for evolution acceptance items are displayed in Table 3.1. In addition, the reliability was calculated for higher and lower ability students, the results of which are also included in Table 3.1.

| | Alpha | G6 |
|-----------------------|--------------|-----------|
| All | 0.82 | 0.83 |
| Higher ability | 0.82 | 0.84 |
| Lower ability | 0.78 | 0.8 |

Table 3.1 Internal consistency of evolution acceptance items (N=3562).

These scores are acceptable and suggest this part of the questionnaire is reliable. This section of the questionnaire also appears to be suitable for higher and lower ability students. However, more detailed analysis of individual questions and the seven aspects of evolution was undertaken. These analyses do not consider abilities separately, given the above suitability.

3.1.1.1 Reliability of individual items

The internal consistency of the questionnaire was tested for the removal of each item. This reflects how the reliability of the questionnaire would change, if individual questions were not included. A score lower than the overall reliability for a questionnaire suggests that an item is reliable: deleting that item would lower the overall reliability of the questionnaire. Conversely, a high score suggests an item is not so reliable: this tends to have a lower inter-item correlation and deleting it will improve the reliability of the questionnaire. The reliability for each of the 14 items is shown in Table 3.2. The correlation of each item with the rest of the items is also shown in this table.

| Item | Alpha if item deleted | G6 if item deleted | Item-rest correlation |
|------|-----------------------|--------------------|-----------------------|
| Q1 | 0.80 | 0.81 | 0.63 |
| Q2 | 0.80 | 0.82 | 0.53 |
| Q3 | 0.80 | 0.81 | 0.63 |
| Q4 | 0.80 | 0.81 | 0.58 |
| Q5 | 0.81 | 0.83 | 0.37 |
| Q6 | 0.83 | 0.84 | 0.17 |
| Q7 | 0.81 | 0.82 | 0.43 |
| Q8 | 0.80 | 0.81 | 0.59 |
| Q9 | 0.81 | 0.82 | 0.42 |
| Q10 | 0.82 | 0.83 | 0.34 |
| Q11 | 0.81 | 0.82 | 0.50 |
| Q12 | 0.80 | 0.81 | 0.55 |
| Q13 | 0.82 | 0.83 | 0.27 |
| Q14 | 0.82 | 0.83 | 0.27 |

Table 3.2 Reliability if an item is deleted and item-rest correlation between each item and all other items (N=3562). Overall internal consistency values can be found in Table 3.1 for comparison. (This table shows combined analysis from all pre, post and retention data. Analyses of the questionnaire at each of these stages showed a similar pattern and the can be found in the supplementary materials.)

Eleven questions show good inter-item consistency: the questionnaire would be less reliable without them. Two items (questions 13 and 14) do not appear to affect the reliability of the question. Question 6 however does not appear to be so

reliable: the internal consistency of the questionnaire would improve if this item was dropped. This item is shown in Figure 3.1.

| | | | | |
|---|-------|-----------|----------|----------------------|
| 6. It is not possible to scientifically disprove the theory of evolution. | | | | |
| Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |

Figure 3.1 Item 6 in the student questionnaire.

All reliable items should correlate with the total. Items with an item-rest correlation of with less than 0.3 are considered potentially problematic as this item does not correlate very with the assessment instrument overall (Field *et al.* 2012). Again, 11 of the questions appear reliable: they have correlations of greater than 0.3. Questions 13 and 14 are slightly below this, but it is question 6 that is of real concern with an item-rest correlation of only 0.17.

3.1.1.2 Reliability of aspects of evolution items

Internal consistency of each of the seven aspects of evolution identified in 2.1 (after Rutledge and Warden 1999 and Lovely and Kondrick 2008) was tested. Due to the low number of items (two), it was anticipated that reliability would be considerably lower than that of the overall evolution acceptance section. Scores are shown in Table 3.3.

The first four aspects of evolution show reasonable reliability according to alpha. G6 is more affected by the lower number of items for each aspect. Geological time and scientific community are both somewhat lower; however it is the reliability of the testability item that is of concern. Question 6 is once again implicated.

| Aspect of evolution | Agree | Disagree | Alpha | G6 |
|-----------------------------|-------|----------|-------|------|
| Human evolution | Q3 | Q12 | 0.69 | 0.52 |
| Evidence for evolution | Q4 | Q2 | 0.67 | 0.5 |
| Dinosaurs and humans | Q13 | Q7 | 0.66 | 0.49 |
| Explanation for modern life | Q1 | Q8 | 0.66 | 0.49 |
| Scientific community | Q5 | Q11 | 0.49 | 0.33 |
| Geological time | Q14 | Q9 | 0.41 | 0.25 |
| Validity | Q10 | Q6 | 0.19 | 0.11 |

Table 3.3 Internal consistency for aspects of evolution (N=3562). These are ranked by their alpha score. Again, combined analysis from all pre, post and retention data are shown. Further analyses can be found in the supplementary materials.

There are various reasons why items may not correlate well to their corresponding aspect. Although questionnaires focus on particular evolutionary concepts, they are not always the exact opposite and acceptance of one doesn't mean complete rejection of the other. For example, consider the two items related to geological time (Figure 3.2). Although a student might be sure that the earth is a lot older than 20,000 years old and select "Disagree" (item 9), they may not think that the earth is 4-5 billion years older either (item 14), and therefore may also select "Disagree".

| | | | | |
|--|-------|-----------|----------|-------------------|
| 7. The age of the earth is less than 20,000 years. | | | | |
| Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
| ----- | | | | |
| 13. The age of the earth is approximately 4-5 billion years. | | | | |
| Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |

Figure 3.2 Geological time items used to assess students' acceptance of evolution in the student questionnaire.

Additional insight was gained on human evolution from students who annotated their questionnaires. For example, students who rejected item 3 were expected to accept item 12 (this can be found in Figure 2.1). However, this was not always the case. A couple of students commented next to their answers that, although they did not accept human evolution, they followed an Islamic belief that there were physically bigger or taller humans in the past. Therefore the two items for these students did not correlate as expected.

As these examples demonstrate, a low alpha does not in itself mean that the questionnaire is not reliable, just that student views do not always fit with those expected. These examples are only likely to be found among a small number of students, hence why large and diverse sample sizes are important. A greater number of items associated with each aspect may help improve consistency of answers.

Despite this explanation, it was clear that certain items needed further consideration. In order to better understand how items measured student acceptance of evolution, and what, if anything, was different about the items which showed less consistency with other items, the spread and skew of data were investigated. Figure 3.3 shows the overall shape of evolution acceptance data.

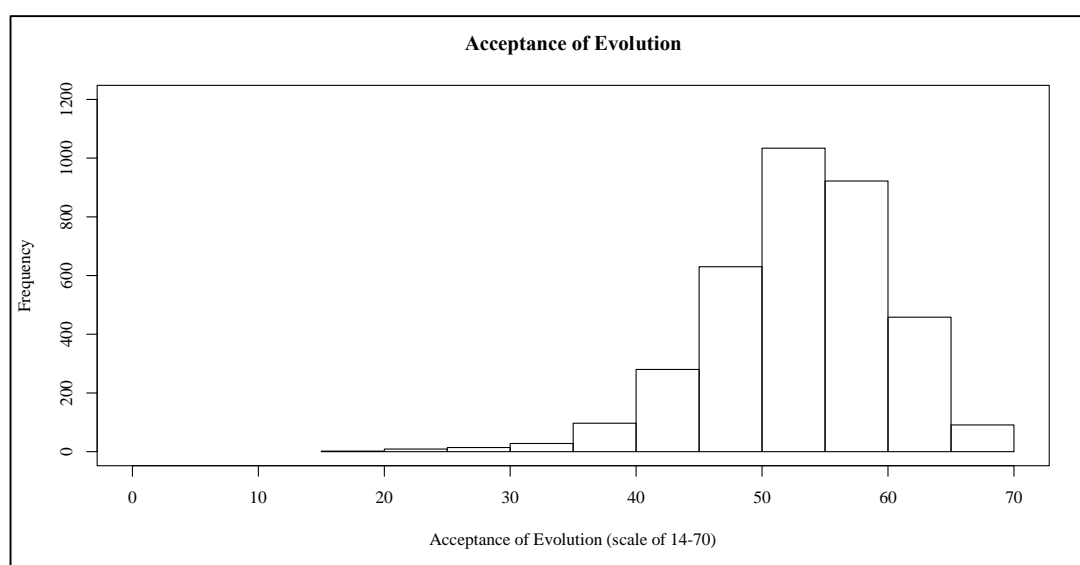


Figure 3.3 Overall evolution acceptance responses (N=3565).

Although not the purpose of this analysis, it is clear that the data show an overall skew towards evolution acceptance, as seen in Figure 3.3. Figure 3.4 shows the spread of data for each of the evolution acceptance items (these are grouped by aspect of evolution).

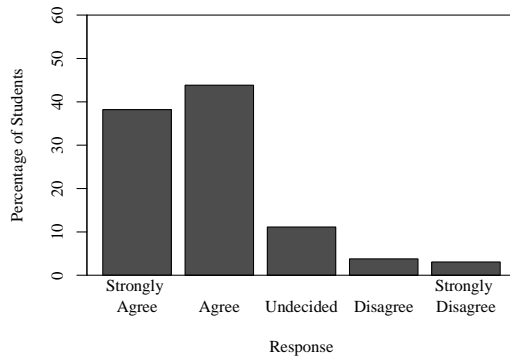
All individual items follow the same skewed trend as the overall data, with the exception of question 6. Table 3.4 shows the extent of this skew. (The meaning of these findings within the context of the research will be discussed further within the following chapters).

All questions skew significantly from the expected random value. Interesting, this includes question 6, however this is by a very small amount, especially compared to others. This is not considered important, and when broken down into pre, post and retention components, this item does not show skew significantly (see supplementary materials). Significance in this instance was determined by Monte Carlo randomization tests.

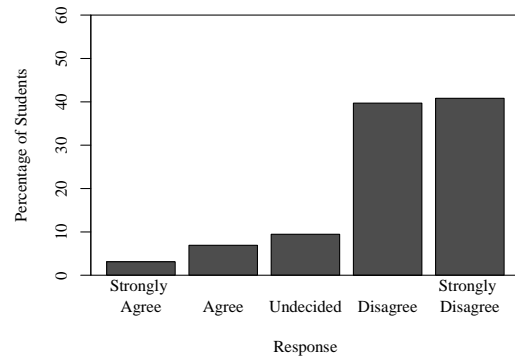
In summary, the evolution acceptance section of the student questionnaire is reliable and has good overall consistency. Most of the different aspects of evolution correlate well. There are some items that are less consistent than others, particularly question 6. This item does not appear to be informative about student acceptance of evolution and removal of this item would increase overall questionnaire reliability.

Human evolution

3. Modern humans are the product of evolutionary processes that have occurred over millions of years

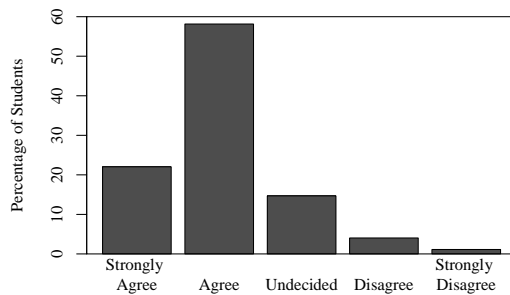


Q12. Humans exist today in the same form in which they always have

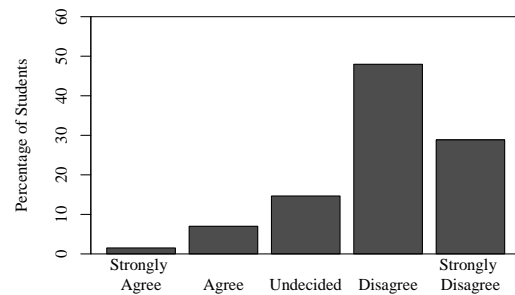


Evidence for evolution

Q4. There are large amounts of factual, historical, and laboratory data that support evolutionary theory

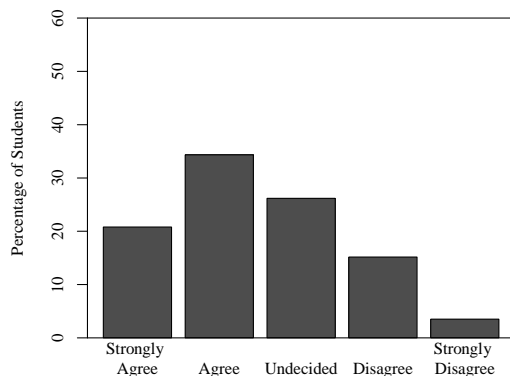


Q2. The theory of evolution is based on guesswork and not valid scientific observation and evidence

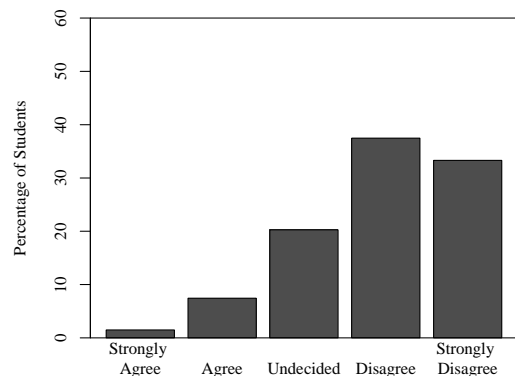


Dinosaurs and humans

Q13. Dinosaurs and humans have never existed at the same time

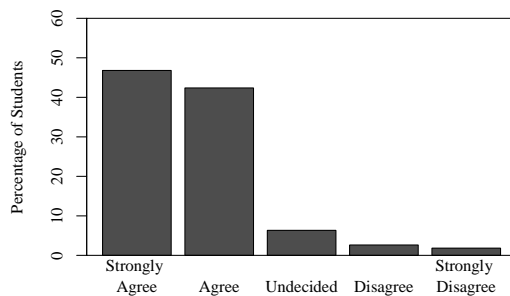


Q7. The first humans lived at the same time as dinosaurs

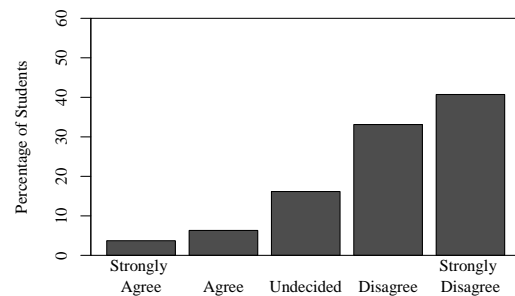


Evolution as an explanation for modern life

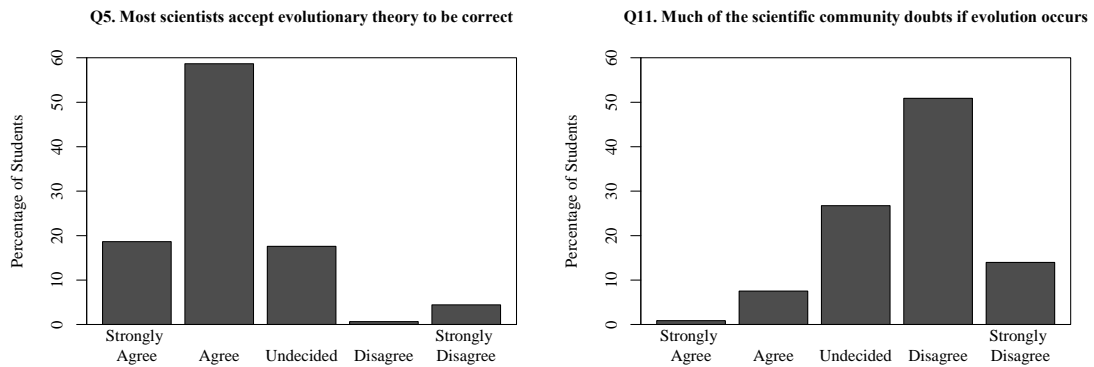
Q1. Plants and animals that are alive today are the result of evolutionary processes that have occurred over millions of years



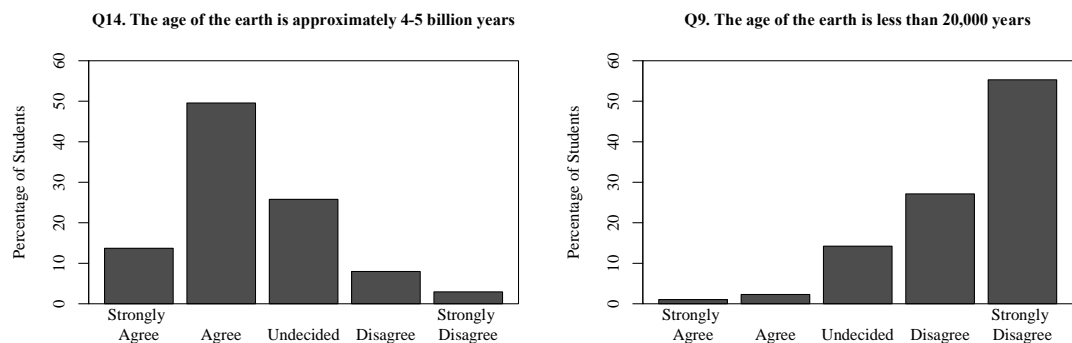
Q8. The theory of evolution cannot be correct since it disagrees with religious accounts of creation



Scientific community's view of evolution



Geological time



Validity of evolution as a scientific theory

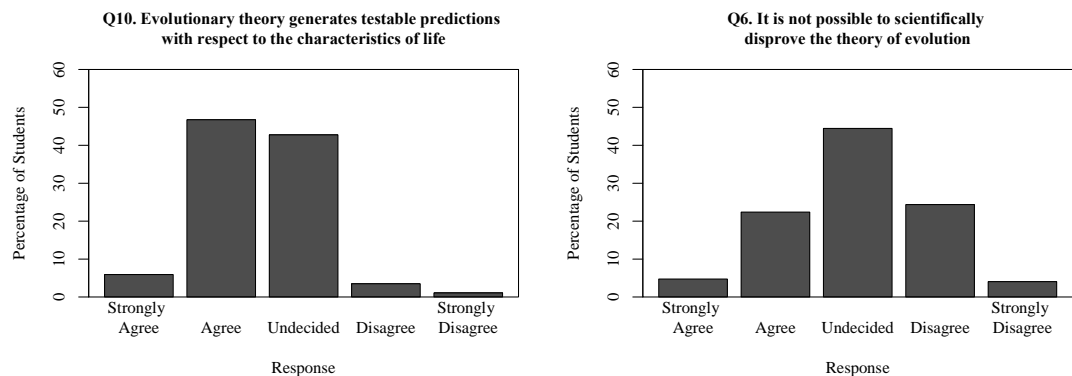


Figure 3.4 Bar charts showing overall percentage of responses to evolution acceptance items. Items are paired by their aspect of evolution (N=3573). Within each pair, the item to the left requires an 'agree' answer for high evolution acceptance, whereas the item to the right requires a 'disagree' response.

| Question | Mean | Skew | p-value | N |
|----------|--------|---------|---------|------|
| Q1 | 4.2970 | -1.5959 | 0.0001 | 3562 |
| Q2 | 3.9559 | -0.9152 | 0.0001 | 3540 |
| Q3 | 4.1033 | -1.3155 | 0.0001 | 3535 |
| Q4 | 3.9591 | -0.9564 | 0.0001 | 3549 |
| Q5 | 3.9016 | -0.7734 | 0.0001 | 3546 |
| Q6 | 3.0062 | -0.0673 | 0.0045 | 3533 |
| Q7 | 3.9365 | -0.7238 | 0.0001 | 3542 |
| Q8 | 4.0082 | -1.0381 | 0.0001 | 3537 |
| Q9 | 4.3331 | -1.2760 | 0.0001 | 3543 |
| Q10 | 3.5294 | -0.3567 | 0.0001 | 3491 |
| Q11 | 3.6956 | -0.5256 | 0.0001 | 3535 |
| Q12 | 4.0819 | -1.2394 | 0.0001 | 3541 |
| Q13 | 3.5371 | -0.3765 | 0.0001 | 3515 |
| Q14 | 3.6315 | -0.7372 | 0.0001 | 3506 |

Table 3.4 Skew of each evolution acceptance item.

3.1.2 Genetics and evolution understanding

Internal consistency of evolution and genetics understanding questions has also been calculated. Given that each question in these sections measures different knowledge within these subject areas and, in order to detect small changes in understanding, these sections should not be too homogeneous, i.e. differences between the questions should be detectable, higher reliability scores are not so desirable. Internal consistency for these sections, and for different abilities, are shown in Tables 3.5 and 3.6.

| | Alpha | G6 |
|-----------------------|-------|------|
| All | 0.77 | 0.82 |
| Higher ability | 0.76 | 0.81 |
| Lower ability | 0.78 | 0.85 |

Table 3.5 Internal consistency of genetics knowledge items (N=3562).

| | Alpha | G6 |
|-----------------------|--------------|-----------|
| All | 0.25 | 0.22 |
| Higher ability | 0.25 | 0.22 |
| Lower ability | 0.26 | 0.24 |

Table 3.6 Internal consistency of evolution knowledge items (N=3562).

Genetics knowledge questions show high internal consistency and if anything, are too homogeneous, whereas evolution knowledge show very low internal consistency. This is likely to be, in part, due to the low number of items within this section, but also shows that the questions were highly discriminating. There is little difference in reliability between higher and lower ability students.

3.2 Item difficulty

Item difficulty is defined as the proportion of respondents who answered a question correctly. The lower the proportion of respondents who get the question right, the more difficult the item is (Kaplan and Saccuzzo 2005). Item difficulty has been calculated for knowledge of genetics and evolution questions, and is shown in Table 3.7. (This can't be calculated for evolution acceptance questions as these do not have a 'correct' answer.)

The acceptable difficulty of questions depends on the purpose of the test. Optimum difficulty level is generally recognised as approximately halfway between 100% of respondents getting the item correct and the level of success expected by chance alone. However in order to discriminate between respondents, most tests include a variety of difficulty levels. For most tests, difficulty ranges between 0.30 and 0.70 tend to maximise information about the differences among respondents (Kaplan and Saccuzzo 2005).

Questions 18 to 26 on the student questionnaire have four possible answers. The probability of getting the right answer by chance is therefore 0.25. The difference between this and all respondents getting the correct answer (1.00) is 0.75, half of

which is 0.375. The optimum item difficulty level can therefore be calculated as follows:

$$0.375 + 0.25 = 0.625 = 62.5\%$$

This proportion is used as guidance in assessing the item difficulty of all knowledge questions. Questions 15, 16 and 17 had different numbers of possible answers and do not lend themselves to this type of analysis due to all the possible permutations of correct answers; however, this is still seen as a reasonable judge of difficulty.

A wide range of difficulty levels are found in the questionnaire. Difficulty generally decreases between pre and post, as might be expected following teaching of these topics. There are some questions which appear very simple: many of those in question 16 show high proportions of students answering correctly. These questions are likely to be less discriminating. However, there are some parts within question 16 that have far less correct answers, suggesting that scoring each part of the question was the correct decision as this may help differentiate between individuals. A small number of questions have values below that which would be expected from chance, suggesting that these questions are too difficult, or that students are actively choosing against the correct answer and possibly choosing 'distractor' answers instead. Detailed analysis of what these proportions actually mean shall be discussed in the following three chapters.

| Question | Pre | Post | Retention | All (mean) |
|-----------------|------------|-------------|------------------|-------------------|
| Q15 | 24.86 | 42.17 | 35.80 | 33.23 |
| Q16a | 96.86 | 98.96 | 98.77 | 97.93 |
| Q16b | 96.05 | 98.66 | 98.76 | 97.42 |
| Q16c | 95.31 | 98.24 | 98.76 | 96.88 |
| Q16d | 88.00 | 90.78 | 94.08 | 89.75 |
| Q16e | 89.33 | 90.93 | 89.91 | 90.06 |
| Q16f | 23.34 | 28.49 | 43.62 | 27.37 |
| Q16g | 78.25 | 83.84 | 87.26 | 81.44 |
| Q16h | 99.82 | 99.66 | 100.00 | 99.77 |
| Q16i | 81.00 | 82.00 | 89.25 | 82.18 |
| Q16j | 96.35 | 97.70 | 98.80 | 97.11 |
| Q16k | 95.12 | 96.68 | 97.58 | 95.97 |
| Q16l | 95.38 | 97.28 | 98.38 | 96.41 |
| Q16m | 98.05 | 99.37 | 99.38 | 98.73 |
| Q16n | 97.01 | 98.87 | 98.44 | 97.93 |
| Q16o | 92.18 | 95.97 | 99.07 | 94.45 |
| Q16p | 78.01 | 86.92 | 91.03 | 82.99 |
| Q16q | 72.64 | 71.90 | 72.08 | 72.28 |
| Q16r | 27.42 | 32.18 | 37.84 | 30.37 |
| Q16s | 98.30 | 99.30 | 100.00 | 98.89 |
| Q16t | 95.09 | 98.53 | 99.39 | 96.95 |
| Q16u | 87.59 | 96.02 | 99.07 | 92.26 |
| Q16v | 63.54 | 80.10 | 85.67 | 72.65 |
| Q16w | 55.08 | 65.32 | 74.01 | 61.18 |
| Q16x | 49.31 | 57.41 | 57.86 | 53.52 |
| Q17a | 24.50 | 46.54 | 47.40 | 36.13 |
| Q17b | 64.56 | 74.83 | 73.48 | 69.90 |
| Q17c | 82.66 | 88.75 | 93.89 | 86.35 |
| Q17d | 52.46 | 72.84 | 82.17 | 64.26 |
| Q17e | 81.57 | 88.58 | 95.90 | 86.02 |
| Q17f | 61.08 | 66.36 | 68.20 | 64.06 |
| Q18 | 19.23 | 26.78 | 20.00 | 22.48 |
| Q19 | 28.79 | 38.79 | 37.58 | 33.85 |
| Q20 | 63.37 | 65.30 | 77.74 | 65.53 |
| Q21 | 22.34 | 24.10 | 22.70 | 43.56 |
| Q22 | 23.31 | 34.03 | 34.11 | 28.90 |
| Q23 | 34.25 | 50.04 | 58.88 | 21.22 |
| Q24 | 38.79 | 55.98 | 62.17 | 35.62 |
| Q25 | 35.91 | 32.86 | 34.77 | 34.50 |
| Q26 | 38.29 | 38.72 | 44.30 | 39.04 |

Table 3.7 Item difficult for genetics (Q15-20) and evolution (Q21-26) knowledge questions for pre, post and retention tests. (Pre N=1886; post N=1886; retention N=434; overall N=4206).

3.3 Item non-response

Item non-response refers to instances of respondents not answering particular items within a research instrument. It can have a significant impact on the quality of data. Missing data can lead to misinterpretations of analyses of individual questions. For example, if a question appears to have low item difficulty but high non-response, are only the students who understand that question and know the answer responding? Item non-response can also be problematic in analysing data. For example, if a student answers 12 of the 14 evolution acceptance items in a highly accepting of evolution manner but gives no response to two of the questions, should these be scored as zero, hence lowering their overall acceptance score, or should allowances for missing data be made? Missing data require careful consideration.

Missing data due to student absence (i.e. where an individual student completed at least one questionnaire, but was not present when their class completed the questionnaire at a different point in time) are not included in this section; however, this does impact the ability to analyse paired data, as shall be discussed in Chapter 10.

The reasons for item non-response are clearly important, but there is often little or no indication as to why individuals have failed to respond to all items. Potential reasons include accidental skipping of questions, lack of interest or attention, disturbances or distractions, time constraints, not wanting to answer a question (e.g. for personal/faith reasons), not understanding a question or certain words within an item, not knowing how to answer a question, and/or not knowing the answer to a question. Some of these possibilities are external factors and not likely to be due to the design of the questionnaire (although it could be argued that the layout and number of items may impact on these). Others are more directly linked to the research instrument.

Instances of item non-response for the student questionnaire are shown in Table 3.8. These are displayed as a proportion of students present when the

questionnaire was completed at each stage. There were a number of ways in which item non-response occurred:

- A student did not attempt a question – there was no answer;
- A question was answered in an ambiguous way (e.g. two answers circled when only one was required);
- A question was answered in an incorrect way that suggested a student did not understand the instruction for the question (e.g. using the same word as an answer twice in a question that required individual words to be used once only).
- A question was answered in a bizarre or crude manner.

These have not been differentiated between in this analysis: all are recorded as occurrences of item non-response.

| Question | Pre | Post | Retention | All (mean) |
|-----------------|------------|-------------|------------------|-------------------|
| Q1 | 0.23 | 0.39 | 0.30 | 0.31 |
| Q2 | 0.87 | 1.11 | 0.30 | 0.92 |
| Q3 | 1.16 | 1.11 | 0.30 | 1.06 |
| Q4 | 0.82 | 0.65 | 0.00 | 0.67 |
| Q5 | 0.70 | 0.85 | 0.61 | 0.76 |
| Q6 | 1.22 | 1.18 | 0.30 | 1.12 |
| Q7 | 0.87 | 0.98 | 0.30 | 0.87 |
| Q8 | 0.99 | 1.24 | 0.00 | 1.01 |
| Q9 | 0.64 | 0.98 | 1.22 | 0.84 |
| Q10 | 2.33 | 2.42 | 1.52 | 2.29 |
| Q11 | 1.16 | 1.11 | 0.30 | 1.06 |
| Q12 | 0.82 | 1.11 | 0.30 | 0.90 |
| Q13 | 0.76 | 2.55 | 1.82 | 1.62 |
| Q14 | 0.82 | 3.08 | 1.82 | 1.88 |
| Q15 | 4.66 | 5.89 | 1.52 | 4.90 |
| Q16a | 3.55 | 5.44 | 1.22 | 4.14 |
| Q16b | 5.53 | 6.88 | 1.82 | 5.77 |
| Q16c | 5.53 | 6.94 | 1.82 | 5.79 |
| Q16d | 5.36 | 7.66 | 2.43 | 6.07 |
| Q16e | 5.01 | 6.88 | 3.65 | 5.68 |
| Q16f | 8.15 | 10.81 | 9.42 | 9.40 |
| Q16g | 6.29 | 10.02 | 4.56 | 7.72 |
| Q16h | 1.51 | 4.98 | 0.61 | 2.91 |
| Q16i | 5.30 | 10.15 | 6.69 | 7.50 |
| Q16j | 15.43 | 23.05 | 24.32 | 19.51 |
| Q16k | 15.26 | 23.05 | 24.62 | 19.45 |

| Question (cont.) | Pre | Post | Retention | All (mean) |
|-----------------------------|------------|-------------|------------------|-------------------|
| Q16l | 15.49 | 23.05 | 24.92 | 19.59 |
| Q16m | 4.19 | 6.75 | 2.43 | 5.12 |
| Q16n | 4.66 | 7.07 | 2.43 | 5.49 |
| Q16o | 6.17 | 7.27 | 2.13 | 6.27 |
| Q16p | 7.57 | 9.89 | 5.17 | 8.34 |
| Q16q | 6.12 | 9.82 | 6.38 | 7.72 |
| Q16r | 7.40 | 10.87 | 10.03 | 9.12 |
| Q16s | 3.84 | 5.83 | 0.91 | 4.42 |
| Q16t | 5.18 | 6.75 | 0.91 | 5.46 |
| Q16u | 6.64 | 7.86 | 2.13 | 6.75 |
| Q16v | 9.26 | 10.48 | 6.69 | 9.54 |
| Q16w | 10.02 | 12.57 | 7.60 | 10.89 |
| Q16x | 10.95 | 13.88 | 9.12 | 12.03 |
| Q17a | 12.52 | 11.92 | 6.38 | 11.70 |
| Q17b | 15.03 | 11.53 | 4.86 | 12.59 |
| Q17c | 12.00 | 12.12 | 5.47 | 11.45 |
| Q17d | 15.84 | 12.70 | 4.56 | 13.46 |
| Q17e | 14.04 | 12.25 | 3.65 | 12.31 |
| Q17f | 16.66 | 14.15 | 7.29 | 14.72 |
| Q18 | 8.21 | 10.02 | 5.78 | 8.76 |
| Q19 | 6.76 | 8.32 | 4.56 | 7.22 |
| Q20 | 6.35 | 9.04 | 5.78 | 7.44 |
| Q21 | 6.93 | 8.97 | 7.60 | 7.86 |
| Q22 | 12.29 | 12.25 | 9.12 | 11.98 |
| Q23 | 9.03 | 11.13 | 7.60 | 9.80 |
| Q24 | 10.66 | 11.33 | 7.60 | 10.66 |
| Q25 | 12.58 | 11.92 | 8.21 | 11.89 |
| Q26 | 12.99 | 12.05 | 9.42 | 12.26 |

Table 3.8 Percentage item non-response (Pre N=1886; post N=1886; retention N=434; overall N=4206).

Item response varies between items. For this reason, findings throughout Chapters 4, 5 and 6 (and indeed in this chapter) may be presented as a proportion of those who did answer a particular question, where appropriate, and sample size will vary.

Overall, item non-response was higher in Sections B and C than in Section A. Question 16 had the highest levels of non-response. It is thought this may be due to students failing to annotate a question when they thought ‘no’ was the correct

answer. Missing data towards the end of the questionnaires may be due to students running out of time; however, comparisons with item difficulty suggest these students found questions on the last page the hardest. It is therefore difficult to make any conclusions about the reasons for item non-response.

Six different strategies were considered when dealing with item non-response. These are displayed in Table 3.9. Due to the relatively low instances of missing data, none of these approaches appear to make any difference to analyses such as reliability. It was therefore decided to use different strategies within the different types of sections: missing data were awarded a score of '0' in knowledge-based sections and non-response evolution acceptance items were scored as '3'. Students who answered less than half of the questions within the evolution acceptance section were removed from this section. Further information on how these strategies were tested can be found in the supplementary materials.

| Strategy | Advantage | Disadvantage |
|---|---|--|
| 1. Give score of '0' (zero) for every instance of non-response. | <ul style="list-style-type: none"> • Includes all students. • No assumptions about what score a student might have had. | <ul style="list-style-type: none"> • May give students an unjustly low score, i.e. if the question were omitted by accident. • Interferes with evolution acceptance scoring systems, i.e. possible to have a score lower than 14. |
| 2. Remove all students who have missed items. | <ul style="list-style-type: none"> • No assumptions about why students didn't answer questions. • No assumptions about what score a student might have been had. • No awarding of unjustly low or high marks. | <ul style="list-style-type: none"> • Lowers sample size. • May ignore important responses. |
| 3. Delete students who have a high percentage of missing data, e.g. over 50% item non-response. | <ul style="list-style-type: none"> • Removal of the least reliable students. | <ul style="list-style-type: none"> • Still need strategy to deal with remaining students' non-response items. |
| 4. Replace omitted item with the overall mean for that item. | <ul style="list-style-type: none"> • Includes all students • Less assumptions about individual scores. • Does not interfere with evolution acceptance scoring system, i.e. no score can be lower than 14. | <ul style="list-style-type: none"> • Many ways of doing this, e.g. based on overall responses for a particular class or ability, none of which may give a true reflection of the score an individual would have had. |
| 5. Scale up an individual's marks based on their other answers. | <ul style="list-style-type: none"> • Includes all students. • Students receive marks consistent with their responses. • Does not interfere with evolution acceptance scoring system, i.e. no score can be lower than 14. | <ul style="list-style-type: none"> • Assumptions about how questions would have been answered, i.e. that omitted questions would have been answered in a similar way. |
| 6. Replace missing data with an 'undecided' score. | <ul style="list-style-type: none"> • Includes all students. • Does not interfere with evolution acceptance scoring system, i.e. no score can be lower than 14. | <ul style="list-style-type: none"> • Only applicable to evolution acceptance items. • Still need strategy to deal with knowledge non-response items. • Assumptions about how questions would have been answered, i.e. that items were omitted due to student being undecided. |

Table 3.9 Strategies considered for dealing with non-response items.

3.4 Validity

Validity describes whether an instrument measures the quality it is designed to assess (Kaplan and Saccuzzo 2005). The validity of most of the items used throughout the questionnaire had been established when the instruments were originally developed through item analysis by experts within evolutionary biology and science education (e.g. Rutledge and Warden 1999). Although it is acknowledged that previous research studies did not include the age range used within this study, these were taken to be good indicators that questions were valid. In addition, a number of experts within the University of Bath and school teachers were asked for their opinion of the questionnaire, and small amendments were made where necessary (as detailed in Chapter 2).

As outlined in Chapter 2, the content of each section aimed to represent key areas of evolution and genetics that students were likely to have encountered by their academic stage. This did limit some question areas, particularly where there were variations between exam boards and ability tiers. The opinion of teachers in clarifying such discrepancies was important here, although this was balanced between academic views of what these topics should include.

On later reflection of the questionnaire, and following reliability analysis and evaluation of the test items, it was recognised that in attempting to improve item 6, its meaning had become unclear. However, the questionnaire does give a reasonable coverage of key aspects of evolution and genetics for students studying these topics within secondary school.

3.5 Item performance

Overall, the student questionnaire appears to be reliable and valid for secondary school students; however, there are certain items which are less useful. Given its negative impact on internal consistency and its low validity, it was decided to remove question 6 from all analyses. Therefore, evolution acceptance now consists of 13 items and is measured on a scale of 13-65. The internal consistency of the evolution acceptance section is now 0.83 (alpha) and 0.84 (G6), given the removal of item 6.

Throughout this thesis, all questions will still be referred to by their original question number, i.e. question 7 will be referred to as question 7, even though there is now, in effect, no question 6.

It is interesting that both questions 13 and 14 appear to have limited impact on the overall consistency of the questionnaire. Reasons for this were considered and one thought was that both of these questions were on a different page to the other evolution acceptance questions. Could students have paid less attention to these questions, and could this also explain the lower item response? The negative wording of question 13 may also have caused problems with students skipping over the important ‘never’ within this. However, it was decided that these questions were not significantly detrimental to the overall reliability of the questionnaire, and that they did provide value. Therefore these questions remain in all analyses.

3.6 Input error

All questionnaires were completed on paper. Data were manually entered into spreadsheets that used formulae to automatically calculate number of correct answers, etc. Although much time and care was taken when inputting data, there was the potential for error during data input. A selection of questionnaires was re-input to calculate this error.

50 student questionnaires were chosen at random (using <https://www.random.org/>). These consisted of 20 pre, 20 post, and 10 retention questionnaires. These were passed to another education researcher who re-entered the data. Their input was then compared to the original input. Given this information, an error rate of 0.09% has been calculated. All of this error was found within the evolution acceptance section of the questions: none was discovered in the knowledge sections (full details of how this was calculated and variations between questions can be found in the supplementary materials). This will not be represented in figures due to the nature of the scoring system meaning that this error is not of relatively large importance, but will be considered when discussing findings in Chapter 10.

3.7 Summary

The student questionnaire is reliable and valid for use with students of different abilities and of GCSE-level knowledge. Questions are of a suitable difficulty to detect small differences between individual students, yet are accessible to a variety of abilities. The exclusion of question 6 removes the only item which was continually judged to be unsuitable. Varying levels of item difficulty and item non-response should be taken into account when interpreting results. Input error is not considered an important constraint.

Chapter 4. Pre test results

Here I report on the largest survey of UK school students as regards their acceptance and understanding of evolution prior to teaching on the subject. I find that the majority of students are accepting of evolution before they formally learn about the topic in secondary school. Most students have some knowledge of genetics, however they have very little understanding of evolution, before being taught these topics. Higher ability students have higher acceptance of evolution and better knowledge of evolution and acceptance. Perhaps surprisingly, evolution acceptance is only weakly correlated to evolution knowledge but more strongly correlated with genetics knowledge. Evolution and genetics knowledge are also correlated but this is surprisingly weak and not detectable in lower ability students. These results make the hypothesis that teaching genetics might increase evolution acceptance a viable model.

This project represents the first large-scale investigation into evolution acceptance in secondary schools in the UK. It is also the first study we are aware of to consider the impact of genetics knowledge on evolution knowledge and acceptance. Here, student acceptance of evolution and understanding of genetics and evolution is detailed. This is prior to students being taught these topics within the GCSE curriculum in secondary school. For many of these students it is likely that these questionnaires were completed before any formal education in evolution.

In this chapter, evolution acceptance, genetics understanding, and evolution understanding are first considered separately. This includes a mixture of comparisons based on achieving the correct answer, and descriptions of student responses, including misconceptions. Differences between ability levels are also explored. Secondly, the relationships between acceptance and understanding are investigated: is there any correlation between these, even before formal education of these topics? Finally, implications for these results within the classroom are discussed.

4.1 Students accept evolution

The majority of school students are accepting of evolution, even before learning about the topic in secondary school. 70% of students show high acceptance, as shown in Figure 4.1. These categorisations are based on Nadelson and Sinatra (2010), as detailed in the supplementary materials, and summarised in Table 4.1. Combining students who have ‘high acceptance’ and ‘very high acceptance’ reveals that 77% of students accept evolution before they have learnt about it. Of the remaining students, 22% are undecided, and only 1% do not show acceptance towards evolution. This would seem an encouragingly high rate of acceptance.

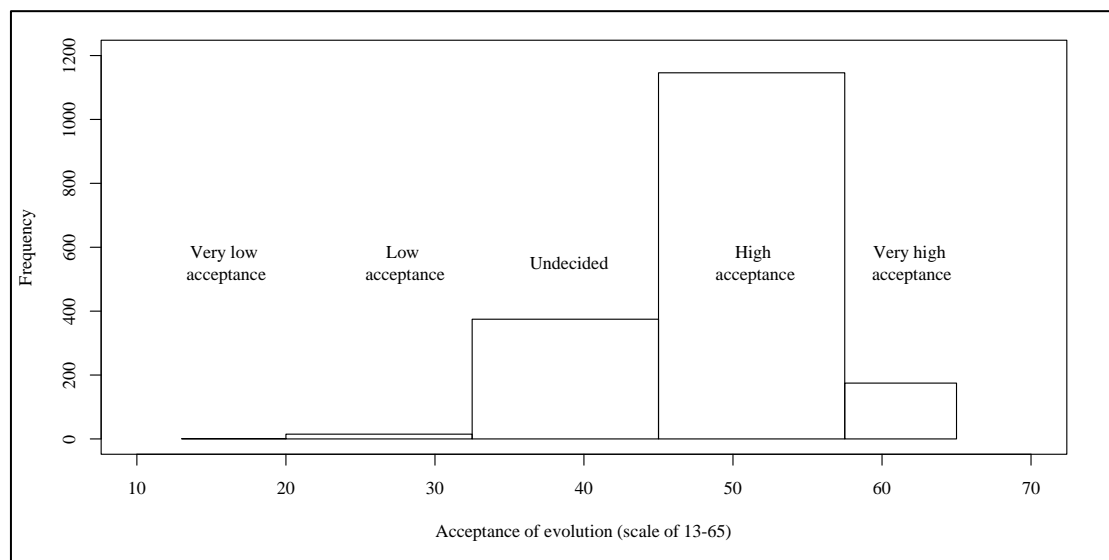


Figure 4.1 Evolution acceptance of students, before learning about evolution (N=1712).

| Acceptance Category | Score (scale of 13-65) |
|---------------------|------------------------|
| Very low | ≤ 19 |
| Low | 20-32 |
| Undecided | 33-45 |
| High | 46-58 |
| Very high | ≥ 59 |

Table 4.1 Categorisation of evolution acceptance. Based on Nadelson and Sinatra (2010), as detailed in the Supplementary Materials).

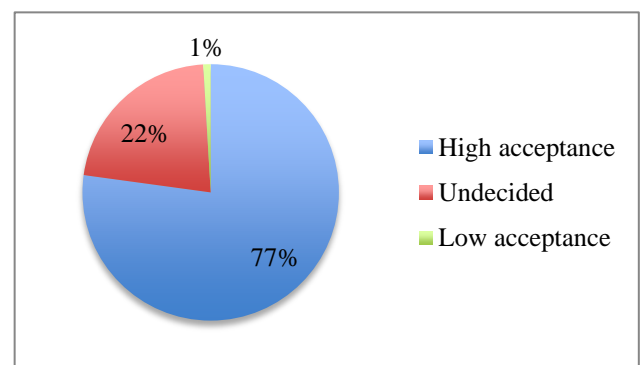


Figure 4.2 Combined evolution acceptance of students, before learning about evolution (N=1712).

4.1.1 Students accept different aspects of evolution

Although overall acceptance of evolution is high, previous research (such as Rutledge and Warden 1999) suggests that acceptance can vary for different aspects of evolution. Acceptance of the seven aspects introduced in Chapter 2 are therefore considered here. As can be seen in Figure 4.3, acceptance does vary between these aspects. Evolution as an explanation for modern life and human evolution show the greatest proportion of acceptance with 79% of students accepting these aspects. Items related to view of the scientific community and dinosaurs and humans are less accepted by students. The validity of the theory of evolution shows particularly low acceptance (just 45% of students) and the highest level of indecision (50% of students); however it should be remembered here that testability is only based on one item, unlike all other aspects. Interestingly, items related to dinosaurs and humans show the greatest levels of rejection (15% of students). Further information and analyses on these can be found in the supplementary materials.

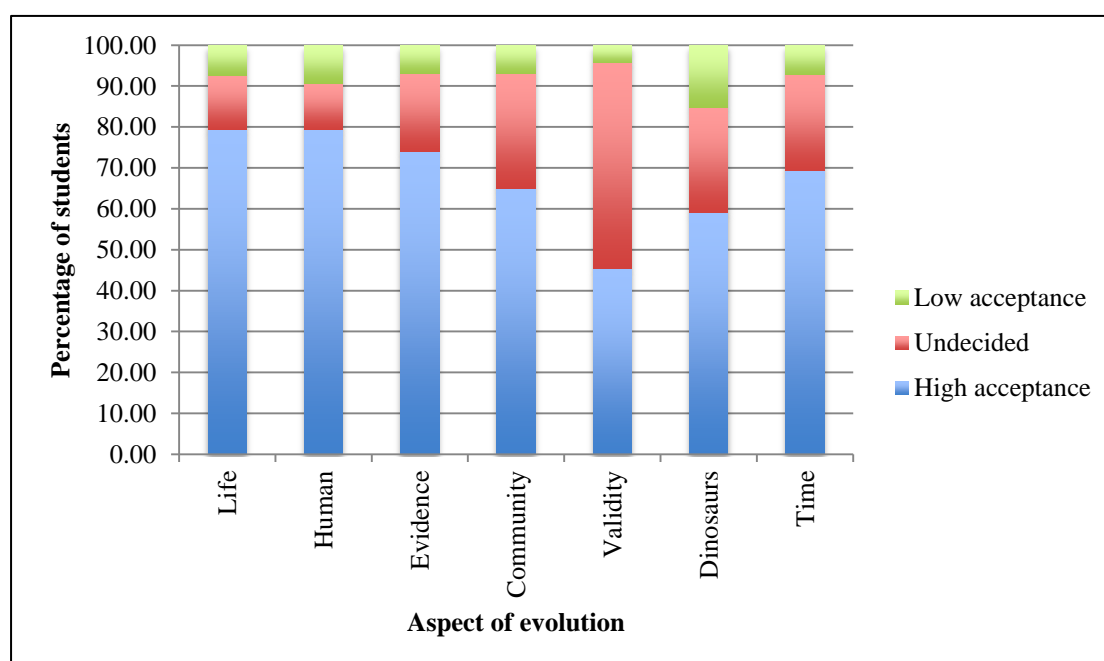


Figure 4.3 Evolution acceptance for the seven different aspects of evolution. The items these aspects are related to are detailed in Figure 2.1 (N=1712).

4.1.2 Higher ability students have greater acceptance of evolution

There is a striking difference between evolution acceptance for higher ability students compared to those who are lower ability. As shown in Figure 4.4, 82% of higher ability students accept evolution but only 61% of lower ability students do. 17% of higher ability students are undecided, compared to nearly 39% of low ability students. But interestingly, lower ability students are no more likely to reject evolution: 1% of higher ability and less 1% of lower ability students display low evolution acceptance.

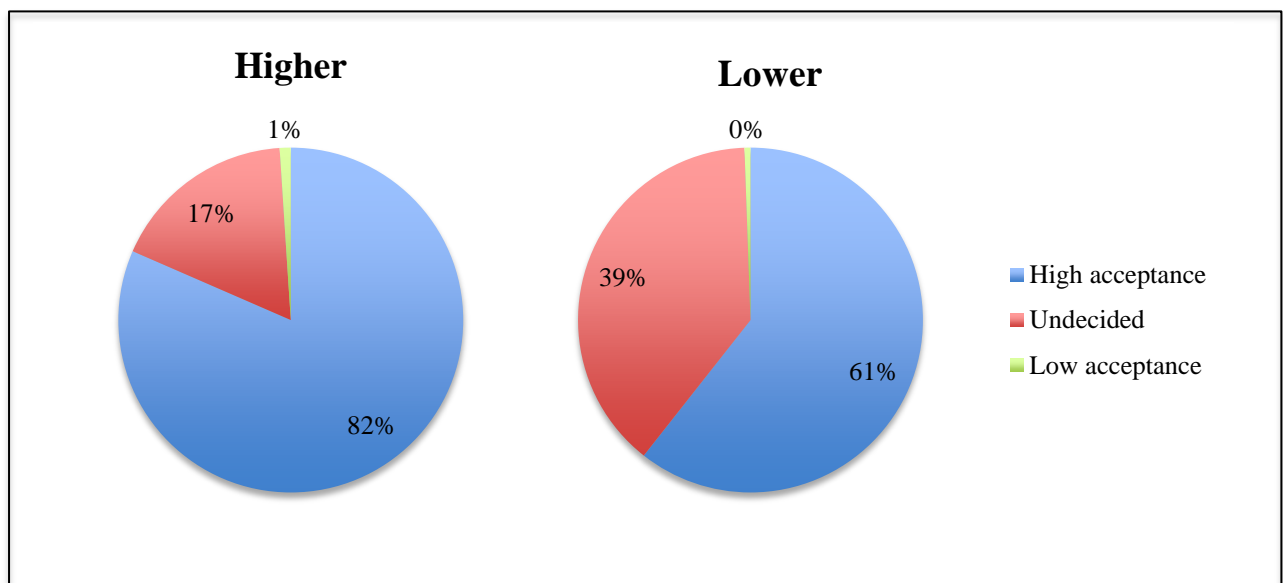


Figure 4.4 Comparison of proportion of evolution acceptance between higher (n=1354) and lower (n=358) ability students.

Although these variations in the proportions of evolution acceptance are striking, in order to better understand the difference between higher and lower abilities, acceptance of individual students is investigated. The average (mean and median) scores for both groups fit within the 'high acceptance' category, as shown in Figure 4.5. However, higher ability students show significantly higher acceptance than lower ability students ($W = 325619.5$, $p < .001$). On average, higher ability students have 6% higher acceptance score than lower ability students. The wider range of values found among higher ability students, particularly the lower outliers, is attributed to the larger sample size.

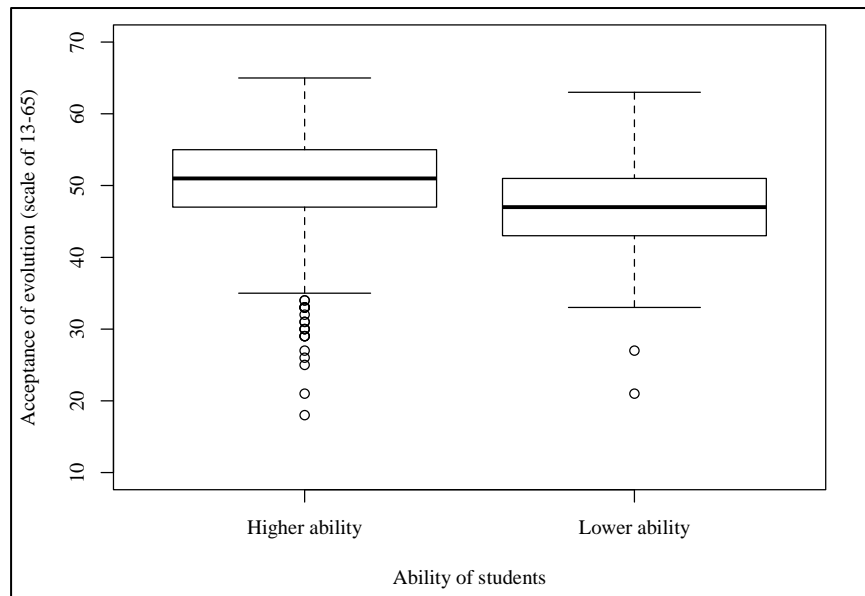


Figure 4.5 Acceptance of evolution for higher and lower ability students before teaching. Each box represents the lower quartile, median, and upper quartile. The ‘whiskers’ or vertical dashed lines to the top and bottom of each box show 1.5 times the inter quartile range. Circles represent outliers (greater than 1.5 time the inter quartile range).

4.2 Students have some knowledge of genetics

Most students have some understanding of genetics before they are taught this topic at GCSE level, as shown in Figure 4.6. The average score is 23 (or 68% correct). This is perhaps to be expected, given that many of the concepts involved in the questionnaire are likely to be introduced at a younger academic level.

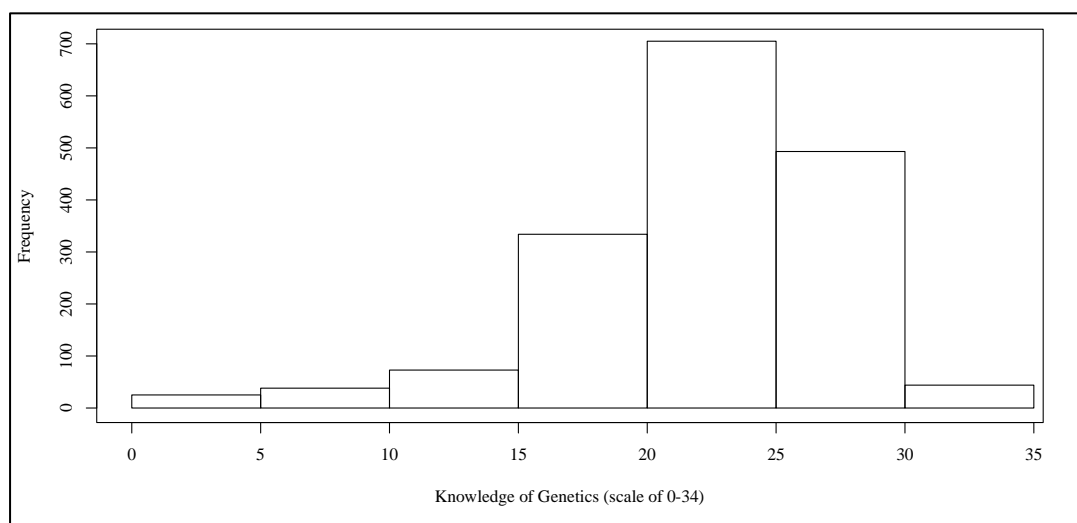


Figure 4.6 Understanding of genetics, before teaching (N=1712).

4.2.1 Variation in student knowledge of genetics

There is much variation between students' responses to individual questions. Some of these reflect the fact that students have not yet been taught the topic, and some represent common misconceptions or difficulties. Findings are summarised in Table 4.2 where the proportion of students present who gave the correct answer is given, along with a classification of knowledge. Although these boundaries are somewhat arbitrary, this nonetheless gives an impression of areas students have knowledge of and those they don't and will provide useful for later comparisons.

Areas that students had good knowledge of were typically part of the 'living organisms' section (Q16). The majority of students were able to classify mammals and insects as living organisms and animals, and as to whether they were made up of cells and contained genetic materials. Interestingly, nearly 27% of students did not recognise humans as being animals. Students struggled more in their understanding of plants, bacteria and viruses, particularly where these questions related to genetic information. 75% of students were unable to correctly identify the sequential relationship between structures (Q15). In particular, there was confusion between genes and chromosomes, with 16% of students selecting genes as being larger than chromosomes. Key terminology was not known by all students (Q17). It is likely that most students will not have learned these words at an earlier educational stage, especially "alleles" which only a fifth of students appeared to know. The most difficult question proved to be related to cell function (Q18): only 18% of students (less than would be expected by chance) correctly identified that different types of cells have different functions because they activate different genes. There was little consensus for this question, but the most common answer was "because they contain different kinds of genes" (32%).

It was expected that many of these questions would not be answered correctly as students have not learnt about this topic yet. However, some of these responses do raise concerns: if students have basic lack of knowledge prior to learning more complex ideas, how will students appreciate key points? For example, genetics teaching commonly begins with Mendelian genetics. How will students understand this topic if they don't know that plants reproduce sexually as well as asexually (Q19)?

| Question | Area | Correct (%) | Knowledge | Alternative answer (s) |
|-----------------|-------------------------------|--------------------|------------------|---|
| Q16h | Animals: giraffes | 98.31 | Good | Giraffes are not animals |
| Q16s | Genetic information: humans | 94.53 | Good | Humans do not contain genetic information |
| Q16m | Cells: humans | 93.94 | Good | Humans are not made up of cells |
| Q16a | Living organisms: humans | 93.42 | Good | Humans are not living organisms |
| Q16n | Cells: giraffes | 92.49 | Good | Giraffes are not made up of cells |
| Q16b | Living organisms: giraffes | 90.74 | Good | Giraffes are not living organisms |
| Q16t | Genetic information: giraffes | 90.16 | Good | Giraffes do not contain genetic information |
| Q16c | Living organisms: moths | 90.04 | Good | Moths are not living organisms |
| Q16o | Cells: moths | 86.49 | Good | Moths are not made up of cells |
| Q16e | Living organisms: bacteria | 84.86 | Good | Bacteria are not living organisms |
| Q16d | Living organisms: oak tree | 83.28 | Good | Oak trees are not living organisms |
| Q16u | Genetic information: moths | 81.77 | Good | Moths do not contain genetic information |
| Q16j | Animals: oak tree | 81.48 | Good | Oak trees are animals |
| Q16k | Animals: bacteria | 80.61 | Good | Bacteria are animals |
| Q16l | Animals: virus | 80.61 | Good | Viruses are animals |
| Q16i | Animals: moths | 76.70 | Good | Moths are not animals |
| Q16g | Animals: humans | 73.33 | Medium | Humans are not animals |
| Q17c | Clone | 72.74 | Medium | Definition/meaning of word |
| Q16p | Cells: oak tree | 72.10 | Medium | Oak trees are not made of cells |
| Q17e | Asexual | 70.12 | Medium | Definition/meaning of word |
| Q16q | Cells: bacteria | 68.20 | Medium | Bacteria are not made of cells |
| Q20 | Genetic engineering | 59.35 | Medium | Confusion between genetic engineering and cloning |
| Q16v | Genetic information: oak tree | 57.66 | Medium | Oak trees do not contain genetic information |
| Q17b | Mutation | 54.86 | Medium | Definition/meaning of word |

| Question (cont.) | Area | Correct (%) | Knowledge | Alternative answer (s) |
|-------------------------|-------------------------------|--------------------|------------------|---|
| Q17f | Genetic variation | 50.90 | Medium | Definition/meaning of word |
| Q16w | Genetic information: bacteria | 49.56 | Medium | Bacteria do not contain genetic information |
| Q17d | Gamete | 44.15 | Medium | Definition/meaning of word |
| Q16x | Genetic information: virus | 43.91 | Medium | Viruses do not contain genetic information |
| Q19 | Plant reproduction | 26.85 | Medium | Plants reproduce asexually |
| Q16r | Cells: virus | 25.39 | Medium | Viruses are not made of cells |
| Q15 | Size sequence | 24.86 | Poor | Relationship between chromosomes and genes |
| Q16f | Living organisms: virus | 21.43 | Poor | Viruses are living organisms |
| Q17a | Alleles | 21.43 | Poor | Definition/meaning of word |
| Q18 | Cell function | 17.65 | Poor | Different types of cells contain different kinds of genes |

Table 4.2 Genetics knowledge before teaching (N=1717). Knowledge is classified as ‘good’ where over 75% of students answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. It should also be noted that questions 18, 19 and 20 are multiple choice questions with four possible answers. The probability of getting the right answer by chance is therefore 25%. The remaining questions are variations on the multiple choice question but have varying numbers or combinations of possible answers.

4.2.2 Higher ability students have more knowledge of genetics

We have seen that most students have some understanding of genetics, prior to learning about the topic. As might be expected, higher ability students have significantly higher understanding of genetics than lower ability students ($W = 349326.5$, $p < .001$). On average, higher ability students score 13% higher (or answer 4.5 more questions correctly) than lower ability students (Figure 4.7).

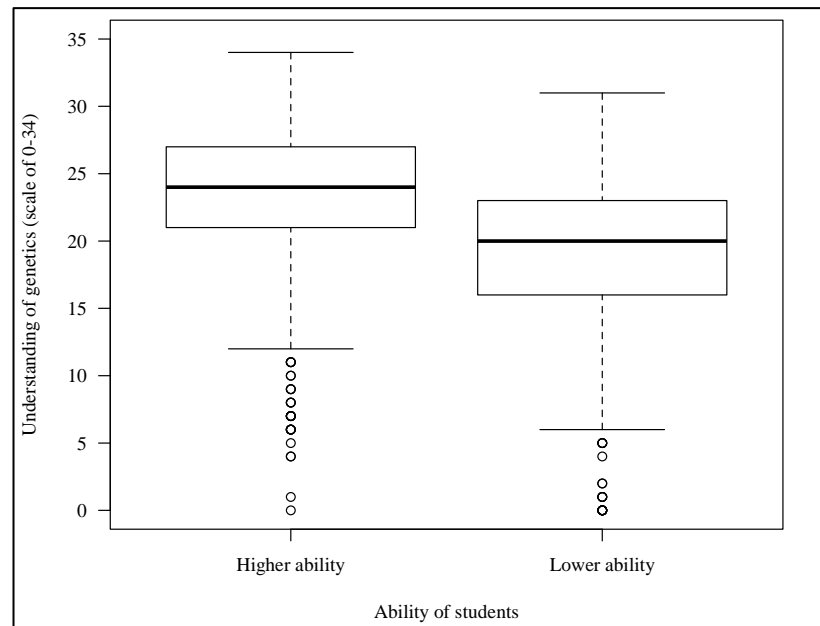


Figure 4.7 Understanding of genetics for higher ($n=1354$) and lower ($n=358$) ability students, prior to learning about genetics.

4.3 Students have little knowledge of evolution

Students have little scientific knowledge of evolution, prior to learning about the topic, as can be seen in Figure 4.8. This is perhaps what we would expect to see, given few students are likely to have learnt about evolution before studying the topic as part of their GCSE curriculum. However, they are a small number of students who clearly do know about evolution: where have they learnt about evolution from previously? It is also interesting that most students are accepting of evolution, yet they don't appear to understand it.

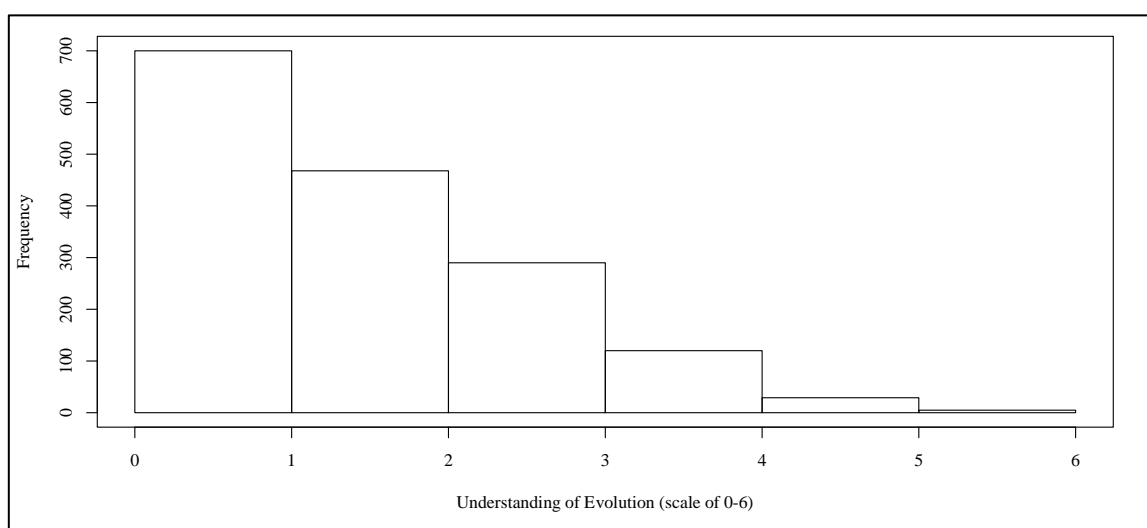


Figure 4.8 Understanding of evolution, before teaching (N=1612).

4.3.1 Variation in student knowledge of evolution

As seen in the previous section on genetics knowledge, many misconceptions were evident among students. These findings are summarised in Table 4.3. Again, the proportion of students present who gave the correct answer is given, along with a classification of knowledge.

| Question | Area | Correct (%) | Knowledge | Alternative answer(s) |
|------------|-------------------------|-------------|-----------|---|
| Q24 | Natural selection | 34.65 | Medium | Inheritance of acquired characteristics |
| Q26 | Geological time | 33.31 | Medium | Lack of knowledge of geological time |
| Q25 | Mechanisms of evolution | 31.39 | Medium | Inheritance of acquired characteristics |
| Q23 | Human evolution | 31.16 | Medium | Humans have evolved from apes |
| Q21 | Definition of evolution | 20.79 | Low | Development of characteristics in response to need; change of simple to complex organisms |
| Q22 | Natural selection | 20.44 | Low | Lack of knowledge of differential reproduction |

Table 4.3 Evolution knowledge before teaching (N=1717). Knowledge is classified as ‘good’ where over 75% of students answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. All questions are multiple choice with four possible answers. The probability of getting the right answer by chance is therefore 25%.

All questions probing evolution understanding were answered correctly by less than 35% of students. The most commonly held misconception was that evolution is the development of characteristics in response to need and that these acquired characteristics can be inherited (Q21, Q24, Q25). There were also students who selected answers pertaining to evolution being the change from simple to complex organisms. Two questions were answered incorrectly by less students than would be expected by chance. These related to defining evolution (Q21) and conditions for natural selection (Q22). It is understandable that students are unlikely to know much about these, prior to learning about the topic formally.

4.3.2 Higher ability students have more knowledge of evolution

As seen for evolution acceptance and genetics knowledge, higher ability students show significantly higher understanding of evolution than lower ability students ($W = 223415.5$, $p < .001$). In contrast to the prior results, this is a relatively modest difference, as shown in Figure 4.9, but due to the small number of questions, this does represent a mean difference of 5% between the two abilities.

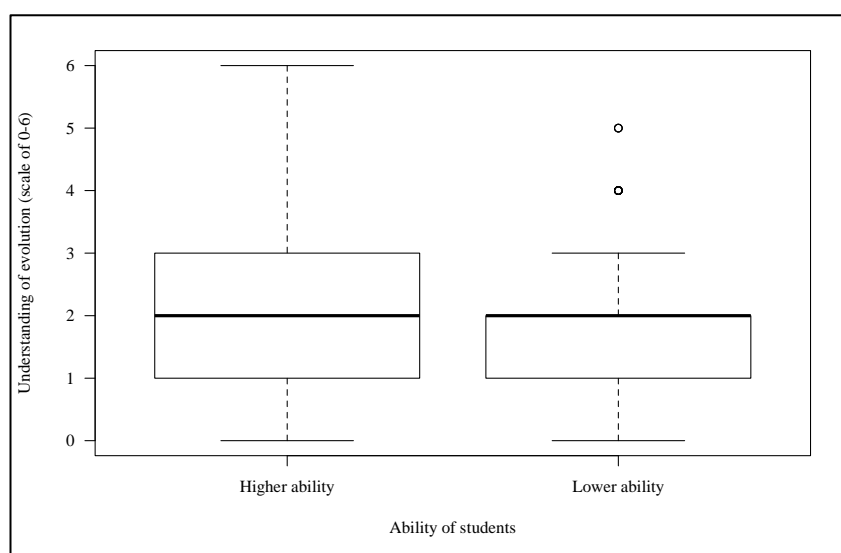


Figure 4.9 Understanding of evolution, for higher (n=1310) and lower (n=301) ability students, prior to learning about evolution.

4.4 Relationships between knowledge and acceptance

With the data in hand we can ask whether there are correlations between acceptance of evolution and understanding of genetics and evolution, even before learning about these topics. Notice that such correlations do not imply causality, but a positive correlation between genetics understanding and evolution understanding would provide credence to the hypothesis being tested in this project, namely that increasing genetic knowledge aids understanding, and possibly acceptance, of evolution.

4.4.1 Knowledge of genetics is positively correlated to acceptance of evolution

Does understanding of genetics predict a student's acceptance of evolution (and vice versa)? We find that there is highly significant, moderate positive correlation ($R_s = 0.43$, $p < .001$) between acceptance of evolution and knowledge of genetics, shown in Figure 4.8.

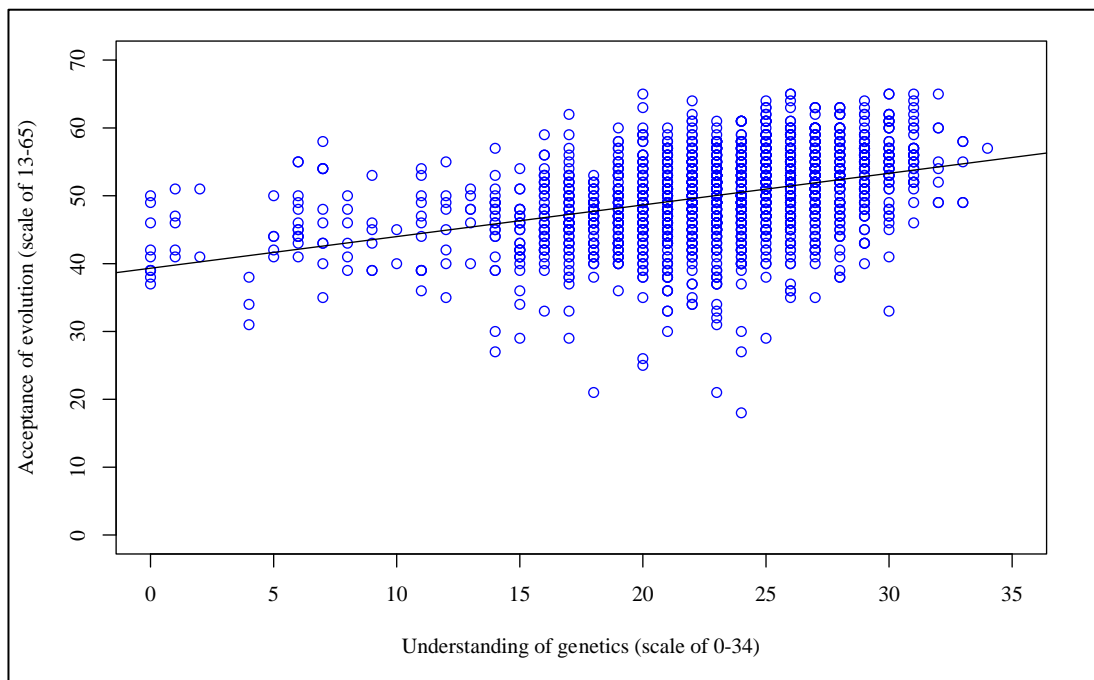


Figure 4.10 The relationship between evolution acceptance and genetics knowledge (N=1712).

4.4.2 Knowledge of genetics is weakly correlated to understanding of evolution

Comparable to the above result, we also find that there is significant, weak positive correlation ($R_s = 0.25$, $p < .001$) between knowledge of genetics and knowledge of evolution, shown in Figure 4.11.

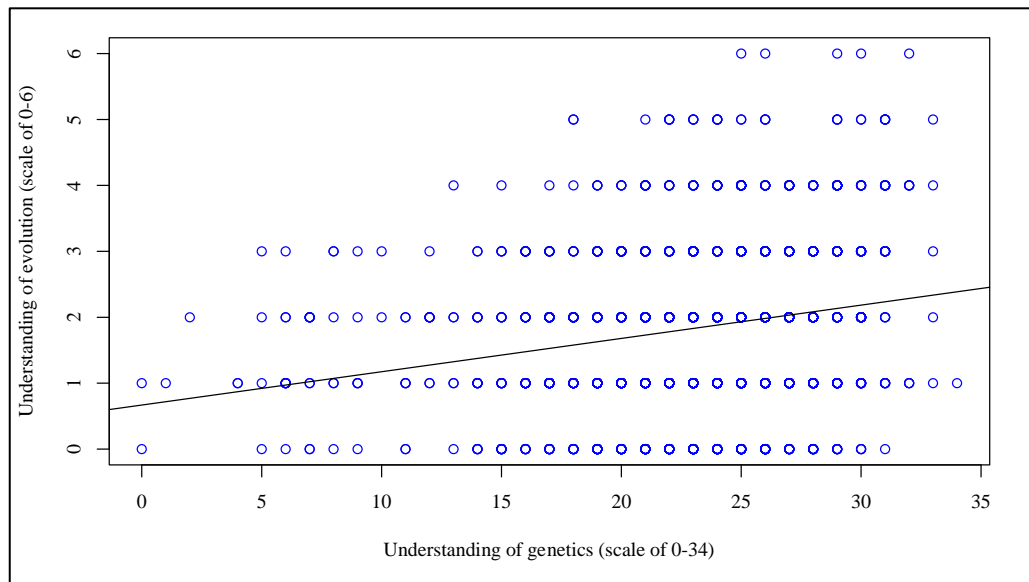


Figure 4.11 The relationship between evolution knowledge and genetics knowledge (N=1717).

4.4.3 Knowledge of evolution is weakly correlated to acceptance of evolution

The above two results provide credence to the view that genetics understanding and evolution acceptance and evolution understanding are correlated. But does understanding of evolution also correlate with evolution acceptance? Curiously, here the correlation is also weak ($R_s = 0.27$, $p < .001$), as seen in Figure 4.12.

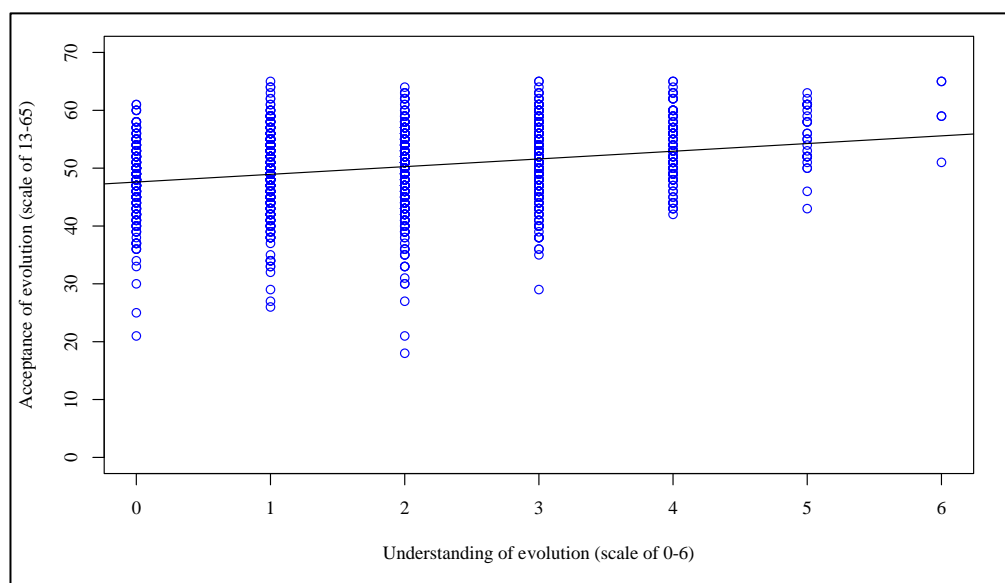


Figure 4.12 The relationship between evolution acceptance and evolution knowledge (N=1717).

In order to better understand the part knowledge plays in acceptance, partial correlations were calculated for the two principal variables. The correlation between evolution acceptance and genetics knowledge, given understanding of evolution is 0.39. The correlation between evolution acceptance and evolution knowledge, controlling for genetics knowledge, is 0.18. Both results are highly significant ($p < .001$). Again, the correlation between genetics knowledge and evolution acceptance is stronger than that between evolution knowledge and evolution acceptance.

While comparing these correlations is difficult, not least because of the different number of questions asked and hence the range of scores, it is notable that the strongest relationship is seen between evolution acceptance and genetics knowledge. Causality here is unclear and may reflect little more than underlying ability (some discussion of this can be found in the supplementary materials). The weakest is between genetics and evolution knowledge. Might this reflect the fact that students are thought to know very little about evolution at this stage as they are unlikely to have formally learnt about this topic. Why then may evolution acceptance be better predicted by knowledge of genetics compared with knowledge of evolution? This we highlight as a most enigmatic result. It also lays

the basis for the hypothesis that teaching genetics may increase both evolution understanding and evolution acceptance.

4.5 Summary and implications for teaching

Over three quarters of students are accepting of evolution even before they have learnt about this topic in school. Only 1% do not accept of evolution. This implies that learning about evolution should not prove problematic for the vast majority of students, and that teachers should not be unduly concerned about introducing the topic. However, the demographics of students should be considered and teachers should be aware of the low level potential for non-acceptance. Higher ability students show higher acceptance than lower ability students. This suggests that acceptance may be linked to ability and understanding. However, lower ability students are not necessarily more likely to reject evolution: they are more undecided.

Most students have some basic understanding of genetics which should provide a useful basis for further learning, but assumptions should not be made about even relatively simple knowledge, such as what living organisms are or the structure of cells. Students have very little knowledge of evolution before learning about evolution. They hold many preconceptions, particularly regarding the development of characteristics in response to need and the inheritability of such traits. Teachers should not assume even basic knowledge of evolution. Higher ability students demonstrate better knowledge of both genetics and evolution but still hold many misconceptions. Teachers should be aware of this and plan to recap basic concepts, particularly with lower ability groups.

There is a relationship between genetics knowledge and evolution acceptance, and to a lesser extent, between evolution knowledge and acceptance. Whether knowledge is causative of acceptance is not clear. Although significant, these relationships are only moderate or weak. Interestingly, genetics knowledge does appear to be a better predictor of evolution acceptance than evolution knowledge, prior to teaching.

Chapter 5. Post test results

Here I compare the pre and post assessment results to ask whether teaching makes any difference and whether teaching order matters. Reassuringly we find strong evidence that teaching has a positive impact on evolution acceptance, evolution knowledge and genetics knowledge. Higher ability students have higher acceptance and knowledge, before and after teaching, compared to lower ability students. Higher ability students also appear to show greater increase in acceptance and understanding than lower ability students, suggesting that current teaching practices work better for higher ability students. Importantly, teaching genetics before evolution has a positive impact on understanding of evolution and genetics, but does not appear to affect acceptance. The relationships between evolution acceptance, evolution knowledge, and genetics knowledge do not appear greatly changed by teaching: all show weak to moderate positive correlation after teaching, similar to before these topics were taught,

In the previous chapter we discovered how the majority of students accept evolution prior to learning about it. We also showed that most students have some knowledge of genetics, but that they do not know much about evolution, before being taught these topics. Additionally, it was shown that evolution and genetics are correlated positively. This chapter compares these results with those found immediately after students have learnt about both evolution and genetics.

Within this chapter we first consider the impact of teaching: does teaching increase students' understanding of evolution and genetics? What impact does teaching have on evolution acceptance? The impact of two variables are then considered. We have already shown that higher ability students have higher acceptance of evolution and understanding of evolution and genetics prior to teaching: what happens to these students compared to lower ability students? Does teaching have a different effect on either group? Topic order is of key interest to this research: if students learn about genetics first, will this help their understanding and acceptance of evolution? In the proceeding chapter it was shown that there is weak positive correlation between acceptance and knowledge.

Here, these relationships are examined after teaching. Finally, teaching implications of these findings are considered.

5.1 The impact of teaching

If the purpose of education is to impart knowledge, then one would hope that teaching has a positive impact on students' understanding of the topics being taught. We examine whether this is the case for evolution and genetics. Whether it is acceptable or even moral for acceptance to be an aim of evolution education is a more contentious issue. The impact that education has on student acceptance of evolution is first investigated.

5.1.1 Teaching has a positive impact on evolution acceptance

The majority of school students are accepting of evolution after learning about the topic. 67% of students show high acceptance, and 18% demonstrate very high acceptance, as seen in Figure 5.1 (using the acceptance categories detailed in Table 4.1). Education has an overall positive impact on evolution acceptance. The proportion of students who accept evolution (high and very high acceptors combined) increases from 77% before teaching to 85%. Now only 14% of students are undecided about evolution. 1% of students still reject evolution, as shown in Figure 5.2.

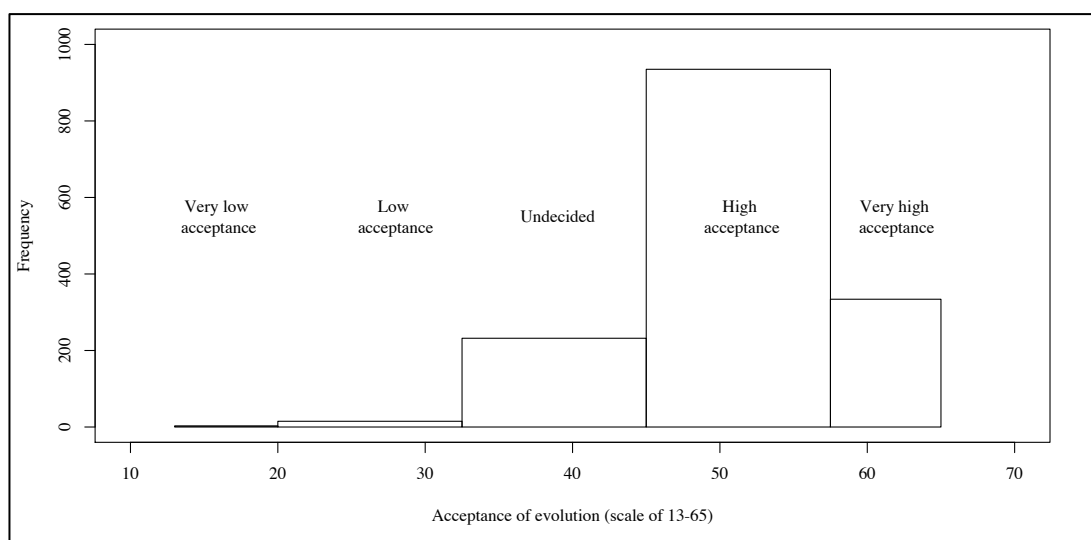


Figure 5.1 Evolution acceptance categories, after teaching (n=1519).

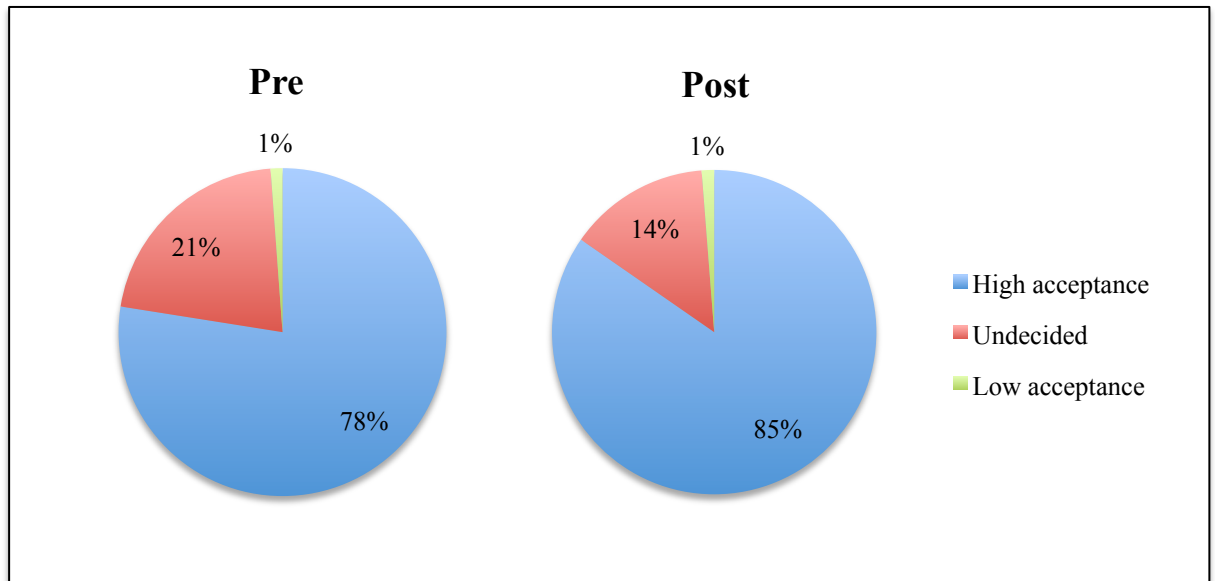


Figure 5.2 Combined evolution acceptance categories, before (n=1712) and after (n=1519) learning about evolution and genetics.

The proportional changes in acceptance categories are shown in Figure 5.3. This details if and how students within each acceptance category change from before to after teaching. Each category is shown as a percentage of the pre category. For example, 100% of students who had ‘very low’ acceptance before teaching have ‘high’ evolution acceptance after teaching. (Note that the sample size should be carefully considered when interpreting this figure: this result for complete increase from very low to high acceptance would appear especially noteworthy. However, given that this actually represents just one student, statistically this is not such an interesting result).

Generally the largest proportion of students stay with their pre teaching category, although there is some variation within most categories. All students who were very highly accepting of evolution prior to teaching remain within the very high or high categorisations; however, 7% of students who accepted evolution in the pre test move into the undecided category after teaching. No students who were accepting of evolution prior to teaching showed rejection of evolution in the post test.

55% of students who were undecided about evolution in the pre test became accepting of evolution after instruction in the subject. However, 42% remain undecided and 2% now reject evolution. Those students who displayed a low acceptance of evolution prior to learning about the topic showed the greatest diversity after teaching: 20% of those who previously rejected evolution are now undecided and 7% now show high acceptance (but again, note should be taken of the relatively low number of students initially within this low acceptance category).

Where then do the 1% who, post teaching, have very low acceptance values come from? The data would suggest that these are all derived from the class that prior to teaching were low, but not very low accepters. Given that the overall trajectory is to increase acceptance post teaching this may reflect nothing more than rare stochastic variation. That is to say, had we repeated the test on a sample that had had no teaching we may have observed similar rates of transfer between low and very low acceptance. Indeed we note that some very high acceptors moved to the class of high acceptors.

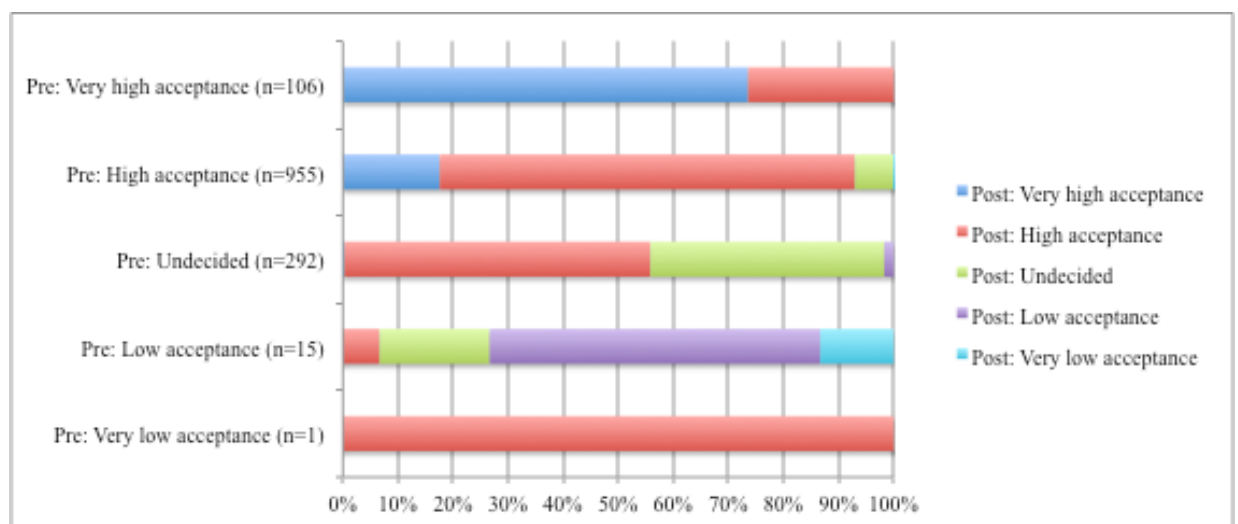


Figure 5.3 Change in evolution acceptance due to teaching. This shows the percentage of students, based on pre test scores, within each acceptance category and their acceptance after teaching (n=1369) Proportion of cohort within each pre teaching acceptance category: very high = 7.7%, high = 69.8%, undecided = 21.3%, low = 1.1%, very low = 0.1%.

5.1.1.1 Students accept different aspects of evolution

There are small differences between individual items and aspects of evolution. Figure 5.4 shows the proportions of acceptance for different aspects of evolution. Compared with those results displayed in Figure 4.3, all aspects show an increase in acceptance, but the overall pattern remains similar with validity remaining the least accepted aspect of evolution. (Further details can be found within the supplementary materials.)

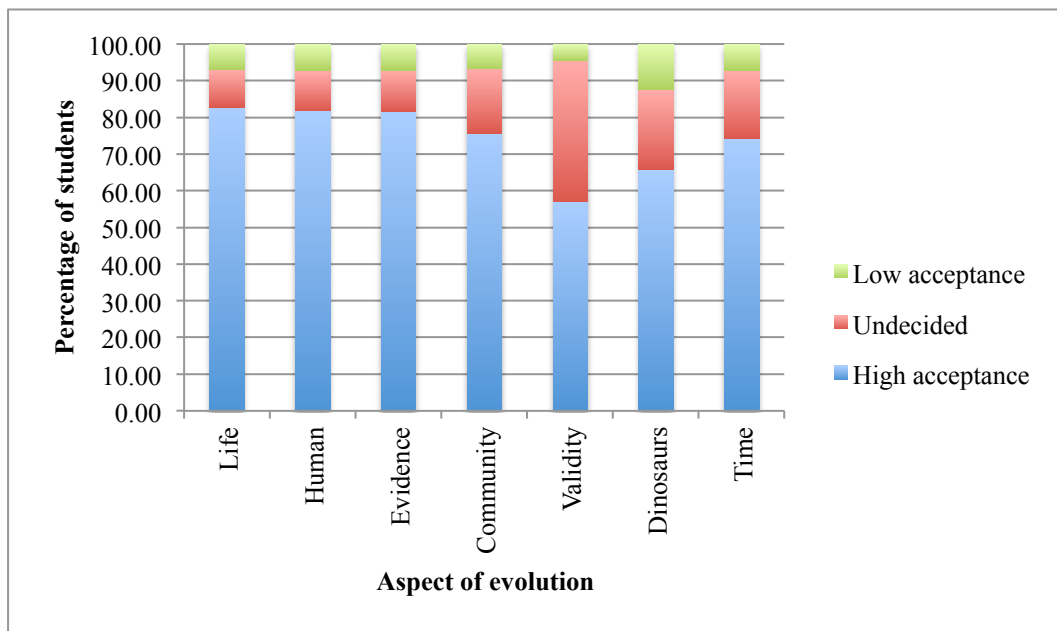


Figure 5.4 Evolution acceptance for the seven different aspects of evolution, after teaching (N=1519).

In order to better understand the changes due to teaching, acceptance scores from individual students are compared. Overall, teaching has a small but highly significant positive impact on students' acceptance of evolution ($Z = 175242.5$, $p < .001$) as shown in Figure 5.5. The average change in score is two, which represents a 3% increase in acceptance. However, acceptance does not increase for all students: two thirds demonstrate a positive change, 9% display no change, and a quarter show a decrease, as shown in Table 5.1. Not all of these changes involve large differences (as is reflected within the relatively small movements in acceptance categories discussed above) but it is quite concerning that such a large proportion of students show some decrease in acceptance.

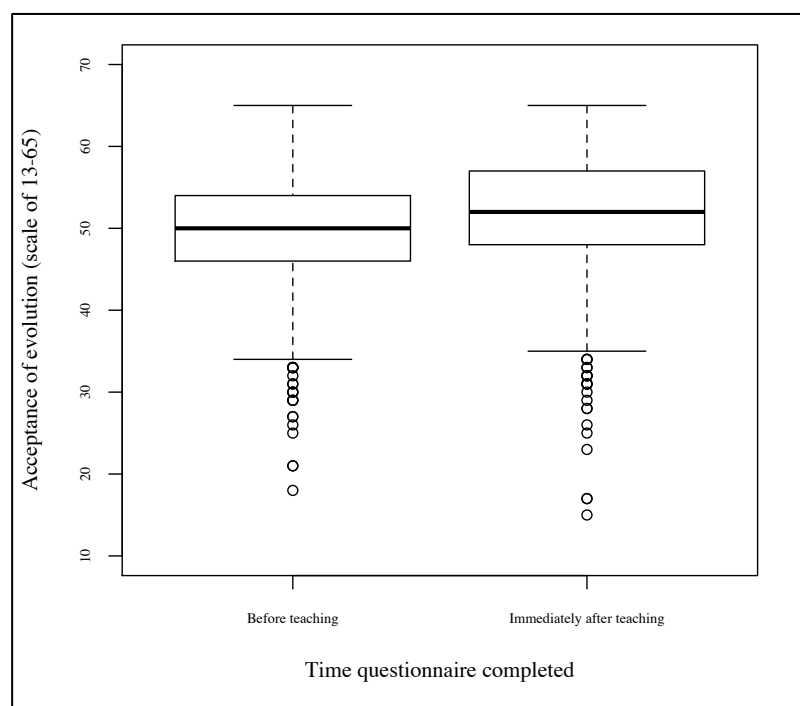


Figure 5.5 Acceptance of evolution, before (n=1712) and after (n=1519) teaching (for an explanation of this type of plot, please refer to Figure 4.5).

| | Positive change | No change | Negative change |
|------------------------|-----------------|-----------|-----------------|
| Number of students | 899 | 128 | 342 |
| Percentage of students | 65.67 | 9.35 | 24.98 |

Table 5.1 Change in acceptance of evolution following teaching (n=1369).

5.1.2 Teaching has a positive impact on knowledge

As might be hoped, teaching has a positive impact on knowledge of genetics, ($Z = 177834$ $p < .001$), as shown in Figure 5.6, and on knowledge of evolution ($Z = 130876.5$, $p < .001$). (A figure related to evolution knowledge can be found in the supplementary materials but is not shown here due to the small increase not being well visualised.) Students increased in genetics knowledge by two marks (6%) on average, and by 0.5 marks (8%) for evolution knowledge, but there was a wide range of variation. Directional changes in scores can be found in Table 5.2. Genetics knowledge is very similar to evolution acceptance with two thirds of students demonstrating an increase in understanding and a quarter showing a decrease. Teaching only had a positive impact on the evolution knowledge of 48% of students. 26% showed no change and 26% showed a decrease in understanding.

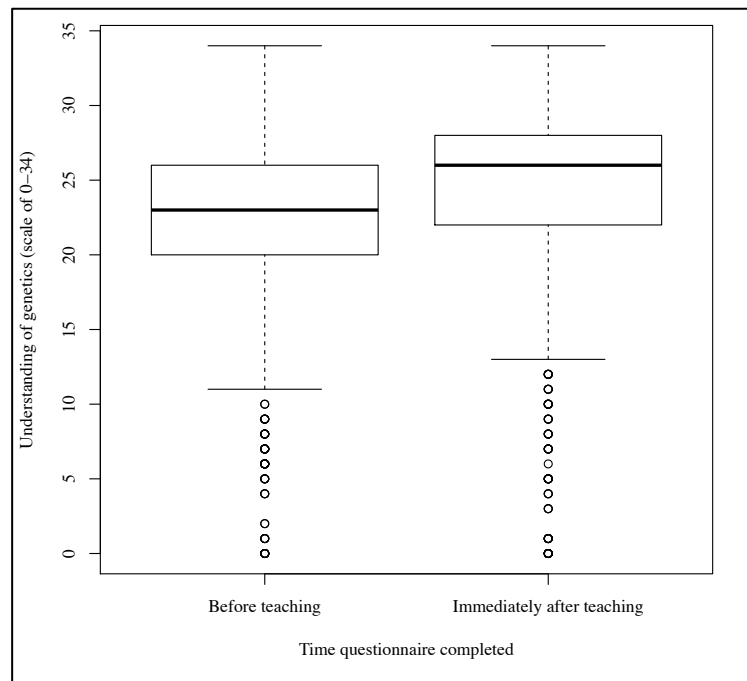


Figure 5.6 Understanding of genetics, before (n= 1712) and after (n=1519) teaching.

| | | Positive change | No change | Negative change |
|------------------------|------------------------|----------------------------|----------------------|----------------------------|
| Genetics Knowledge | Number of students | 893 | 120 | 336 |
| | Percentage of students | 66.20 | 8.90 | 24.91 |
| Evolution Knowledge | Number of students | 589 | 323 | 321 |
| | Percentage of students | 47.77 | 26.20 | 26.03 |

Table 5.2 Change in understanding of genetics and of evolution following teaching (n=1349).

There is much variation among students' changes between acceptance and knowledge, as seen in Table 5.3. 47% of students demonstrate positive change in evolution acceptance and genetics knowledge (not considering change in evolution knowledge). This is greater than the proportions of students who demonstrate positive change in evolution acceptance and knowledge, and in genetics and evolution knowledge. Overall, 24% of students show positive change in evolution acceptance, genetics knowledge and evolution knowledge. It is not the same students who consistently demonstrate no or negative change: only 0.2% and 2.5% of students respectively. It is therefore encouraging that over 97% of students show positive change in at least one of these three areas. The majority of students show a mixture of positive and negative change (Further information can be found in the supplementary materials.)

| Change | Areas | Number | Percentage |
|---------------------------------------|--|--------|------------|
| Positive | Evolution acceptance & genetics knowledge | 572 | 46.66 |
| | Evolution acceptance & evolution knowledge | 412 | 33.61 |
| | Genetics knowledge & evolution knowledge | 411 | 33.52 |
| None | Evolution acceptance & genetics knowledge | 10 | 0.82 |
| | Evolution acceptance & evolution knowledge | 31 | 2.53 |
| | Genetics knowledge & evolution knowledge | 29 | 2.37 |
| Negative | Evolution acceptance & genetics knowledge | 79 | 6.44 |
| | Evolution acceptance & evolution knowledge | 86 | 7.01 |
| | Genetics knowledge & evolution knowledge | 87 | 7.10 |
| All three show positive change | | 294 | 23.98 |
| All three show no change | | 2 | 0.16 |
| All three show negative change | | 30 | 2.45 |

Table 5.3 Proportions of change in acceptance of evolution, understanding of genetics and understanding of evolution, following teaching (n=1226). Note this does not include all possible permutations so percentages shown do not add up to 100%. See supplementary materials for all possible combinations.

5.2 Academic Ability

Having seen how higher ability students have higher acceptance and evolution prior to learning about evolution and genetics, we next question whether higher ability students show greater acceptance and understanding after teaching. We also ask whether there is any difference in the amount of change seen in higher ability students, compared with those in lower ability classes.

5.2.1 Higher ability students have greater acceptance of evolution

Teaching has a positive impact on higher ability students' acceptance of evolution, ($Z = 114312$, $p < .001$), and for lower ability groups of students ($Z = 6374.5$, $p < .001$). However, higher ability students had a greater level of evolution acceptance before teaching than lower ability students, as demonstrated in the previous chapter ($W = 325619.5$, $p < .001$) and now after teaching too ($W = 240955.5$, $p < .001$). These differences are shown in Figure 5.7.

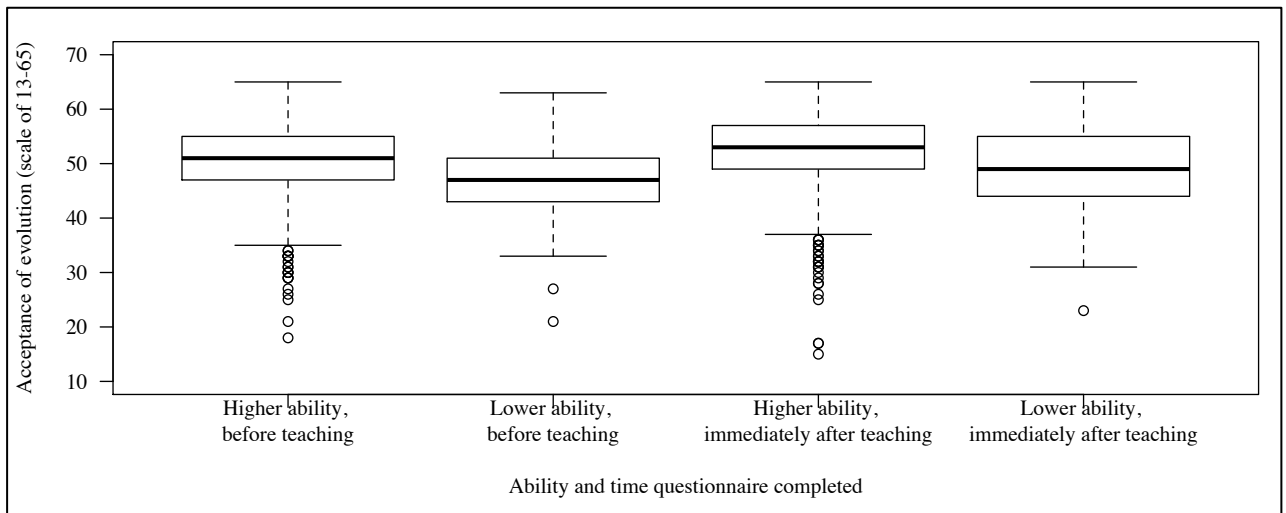


Figure 5.7 Acceptance of evolution for higher and lower ability students, before and after learning about evolution and genetics (higher pre $n=1354$, lower pre $n=358$, higher post $n=1203$, lower post $n=284$).

As these two groups were significantly different before teaching, a ‘linked data’ approach has been taken to further analyse a sub sample of these data. This involves matching students from the smaller sample size (in this case, lower ability students) with a sub section of students from the larger sample size (higher ability here) who have the same pre test scores. (Full description and further analyses can be found in the supplementary materials).

Both groups show a significant increase in acceptance after teaching (higher: $Z = 4765$, $p < .001$, lower: $Z = 6337.5$, $p < .001$). Interestingly there is a significant difference between the groups after teaching: higher ability students show a greater acceptance in evolution, compared to those from lower ability sets, even when students start with the same acceptance ($W = 58036$, $p = .03$). This is confirmed by a comparison of the change in scores for each of the two ability groups ($W = 39617.5$, $p = .008$). This suggests that current teaching practices have a more positive impact on higher ability students.

5.2.2 Higher ability students have more knowledge of genetics

Teaching also has a positive impact on higher ability students’ understanding of genetics ($Z = 114023$, $p < .001$) and for lower ability groups of students ($Z =$

6757, $p < .001$). Again, higher ability students have a greater level of genetics understanding before teaching, ($W = 349326.5$, $p < .001$), and after teaching ($W = 239010.5$, $p < .001$). This is shown in Figure 5.8.

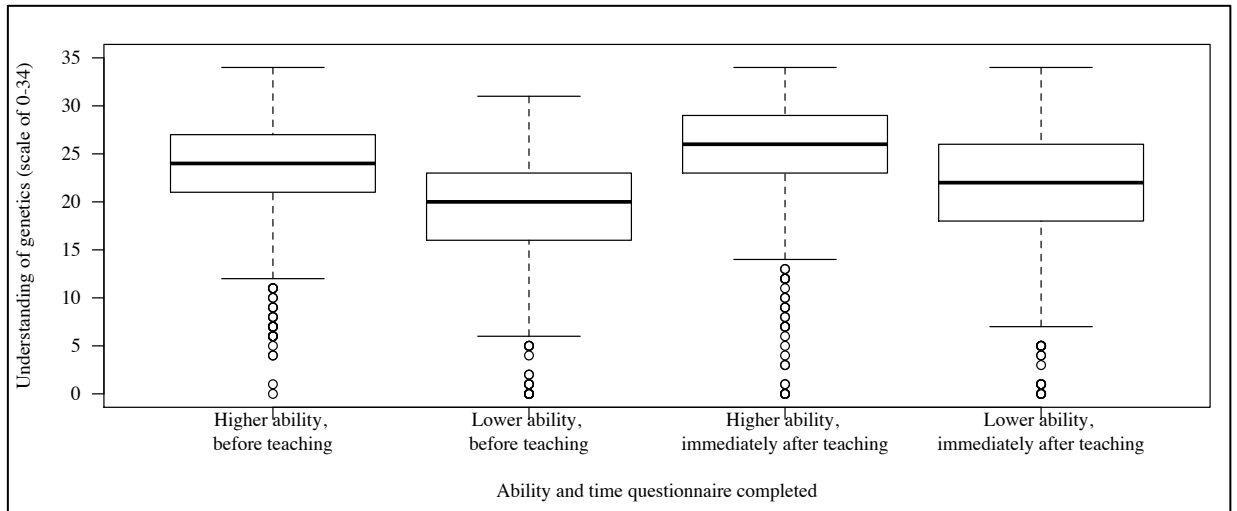


Figure 5.8 Understanding of genetics for higher and lower ability students, before and after learning about evolution and genetics (higher pre $n=1354$, lower pre $n=358$, higher post $n=1203$, lower post $n=284$).

A linked approach has been used again to further analyse the differences between ability groups. Both groups show a significant increase in genetics knowledge (higher: $Z = 3619.5$, $p < .001$, lower: $Z = 6149.5$, $p < .001$). There is a significant difference between the groups after teaching, with higher ability students showing a greater understanding of genetics compared to those from lower ability sets ($W = 52836.5$, $p < .001$), even when students start with the same understanding of genetics. This is confirmed by a comparison of the change in scores for each ability group ($W = 35224$, $p < .001$). Again, this suggests that current teaching practices work best for the higher ability students.

5.2.3 Higher ability students have more knowledge of evolution

As seen for evolution acceptance and genetics understanding, teaching had a positive impact on evolution acceptance for higher ability students ($Z = 95800.5$, $p < .001$) and for lower ability students, ($Z = 2746$, $p < .001$). Again, higher ability

students have a greater level of evolution acceptance before teaching ($W = 223415.5, p < .001$) and after teaching ($W = 169066, p < .001$).

A linked approach has again been taken to further investigate the differences between ability groups. Both groups show a significant increase in understanding evolution (higher: $Z = 2888.5, p < .001$, lower: $Z = 2746, p < .001$). There is a significant difference between the groups after teaching, with higher ability students showing a greater understanding of evolution compared to those from lower ability sets ($W = 43761, p < .001$), even when students start with the same understanding of evolution. Once again this is confirmed by a comparison of the change in scores for each ability group ($W = 23390, p = .003$). This result also indicates that current teaching practices work best for higher ability students.

To summarise these ability results, we find that higher ability students have greater acceptance of evolution and understanding of evolution and genetics both before and after teaching. In addition, higher ability students show a significantly greater amount of increase compared to lower ability students, even where initial differences in scores are controlled for. These findings suggest that evolution and genetics education has a greater impact on higher ability students than it does on lower ability students.

5.3 Topic order

Evolution and genetics are included in some form within all the GCSE exam board syllabi. Their positioning and order varies, and no direct links between topics are made. We hypothesise that if students learn these topics in a particular order, this simple intervention could have a positive impact on learning, i.e. if students are taught genetics prior to learning about evolution, they will have a better understanding of evolution due to their knowledge of heritability. We begin by investigating what impact topic order has on evolution knowledge.

5.3.1 Teaching genetics first increases evolution knowledge

Teaching has a positive impact on genetics knowledge for those students who are taught genetics first ($Z = 42704$, $p < .001$) and for those who are taught evolution first ($Z = 23566$, $p < .001$). The two groups are not significantly different prior to learning these topics ($W = 302352.2$, $p = 0.5$) but those students who were taught genetics first have significantly higher post test scores than those who were taught evolution first ($W = 267270$, $p < .001$). The change in scores was also significantly different, with those learning genetics first showing a greater increase in evolution knowledge ($W = 151199.5$, $p < .001$) as shown in Figure 5.9. Although this change is only small with a mean difference of 0.4 marks, this represents a 7% adjustment in understanding.

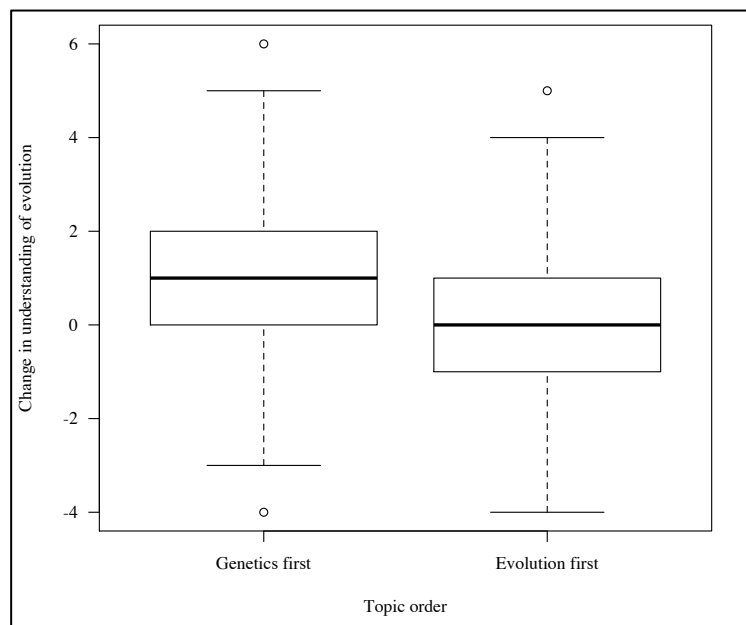


Figure 5.9 Change in understanding of evolution for different topic orders, after teaching (genetics first $n=779$, evolution first $n=454$).

5.3.2 Teaching genetics first increases genetics knowledge

Students taught using either topic order show an increase in genetics knowledge (genetics first: $Z = 63098$, $p < .001$, evolution first: $Z = 28941$, $p < .001$). However, the two groups are significantly different before ($W = 428985$, $p < .001$) and after ($W = 352946.5$, $p < .001$) teaching. A linked data approach has been taken to compare students who had the same understanding prior to teaching. Again, students taught both topic orders show a significant increase in genetics

understanding (genetics first: $Z = 18289$, $p < .001$ and evolution first: $Z = 25277$, $p < .001$), but those who learn about genetics first have significantly higher post test scores than those students who learnt about evolution first ($W = 173251$, $p < .001$), as seen in Figure 5.10. The change in scores is also significantly different, with those learning genetics first showing a greater increase in genetics knowledge ($W = 129838$, $p < .001$). This is shown in Figure 5.11. The change is quite modest; on average scores are 1.1 marks higher, which represents a difference of 3.5%.

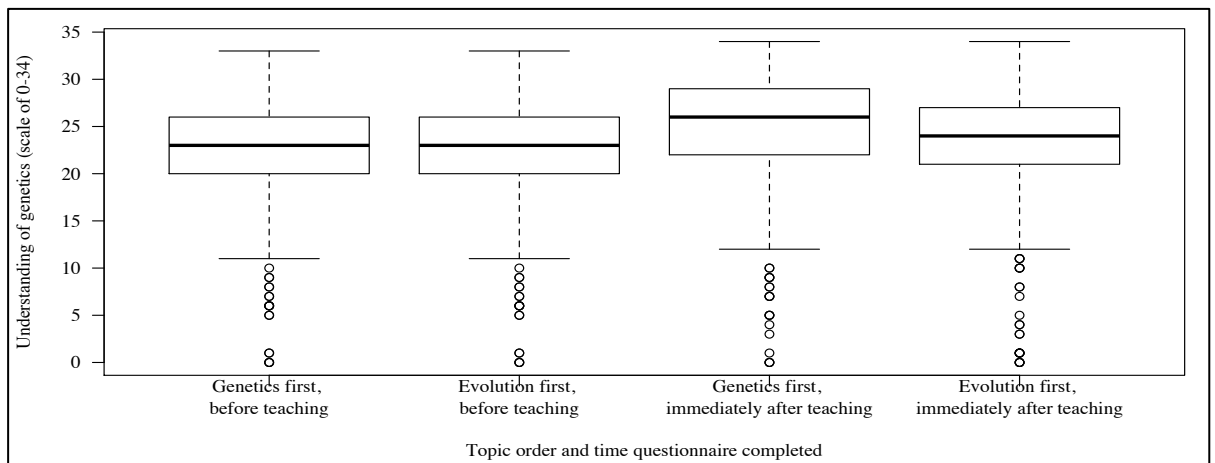


Figure 5.10 Understanding of genetics for different topic orders, before and after learning about evolution and genetics (genetics first, before teaching $n=611$, evolution first, before teaching $n=611$, genetics first, after teaching $n=523$, evolution first, after teaching $n=536$).

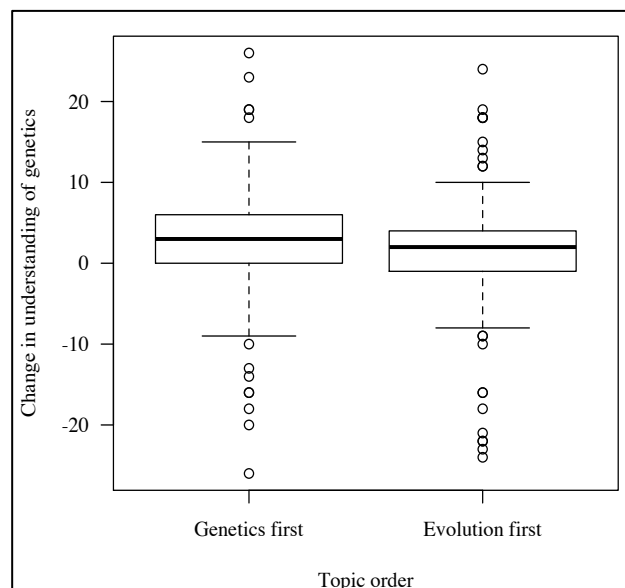


Figure 5.11 Change in understanding of genetics for different topic orders, after teaching (genetics first $n=476$, evolution first $n=472$).

This is a very interesting result as these students learnt about genetics longer ago, so it might be expected that their knowledge may not be so good (although results presented in the following chapter disagree with this). It is intriguing as to why learning about genetics before evolution can help students to understand genetics better. This is not a question considered previously: could better understanding of evolution improve understanding of genetics?

5.3.3 Topic order has no impact on evolution acceptance

Students taught evolution first and students taught genetics first both showed significant increase in evolution acceptance after teaching (genetics first: $Z = 67718$, $p < .001$, evolution first: $Z = 25183.5$, $p < .001$). However, these initial comparisons also revealed that the two groups were significantly different before they learnt about evolution and genetics ($W = 377746.5$, $p = .005$), but not significantly different after learning about these topics ($W = 289152.5$, $p = .07$). The reasons for this are unknown. A linked data approach was taken to compare students who had the same acceptance prior to teaching. There was no significant difference found between the different topics after teaching.

5.4 Ability and topic order

Given these key findings regarding topic order, combined with the strong evidence found that ability has a big impact on evolution acceptance and evolution and genetics understanding, it is important to confirm that the topic order effect observed in the previous section is not merely an artefact of ability. Although this is a random control test, the two groups may not have different compositions with regards to ability. A comparison of the proportion of higher and lower ability students within the two topic orders can be found in Table 5.4. From this it is clear that, for reasons unknown, lower ability students tended to be taught evolution first. Further analysis is therefore needed to distinguish the impact of topic order from that of ability. The different topic orders for both higher and lower ability groups have therefore been compared.

| | Higher Ability | | Lower Ability | |
|------------------------|----------------|----|---------------|----|
| | n | % | n | % |
| Genetics first | 933 | 64 | 212 | 49 |
| Evolution first | 523 | 36 | 218 | 51 |

Table 5.4 Proportions of higher (n=1456) and lower (n=430) ability students taught genetics first and evolution first.

5.4.1 Teaching genetics first increases evolution knowledge for higher and lower ability students

Higher ability students show significant increase in evolution understanding regardless of which topic order they are taught first (genetics first: $Z = 33239.5$, $p < .001$, evolution first: $Z = 15882.5$, $p = .004$). The two groups were not significantly different before teaching ($W = 195495.5$, $p = .7$) but higher ability students who learnt about genetics first demonstrate greater evolution knowledge than those who were taught evolution first ($W = 1777056.5$, $p = .005$). There is a significant difference between the change in scores with those taught genetics first showing the greater increase in knowledge of evolution ($W = 145403$, $p = .005$). The average change was small, representing on average a 6% increase in knowledge of evolution. This change in understanding is shown in Figure 5.12.

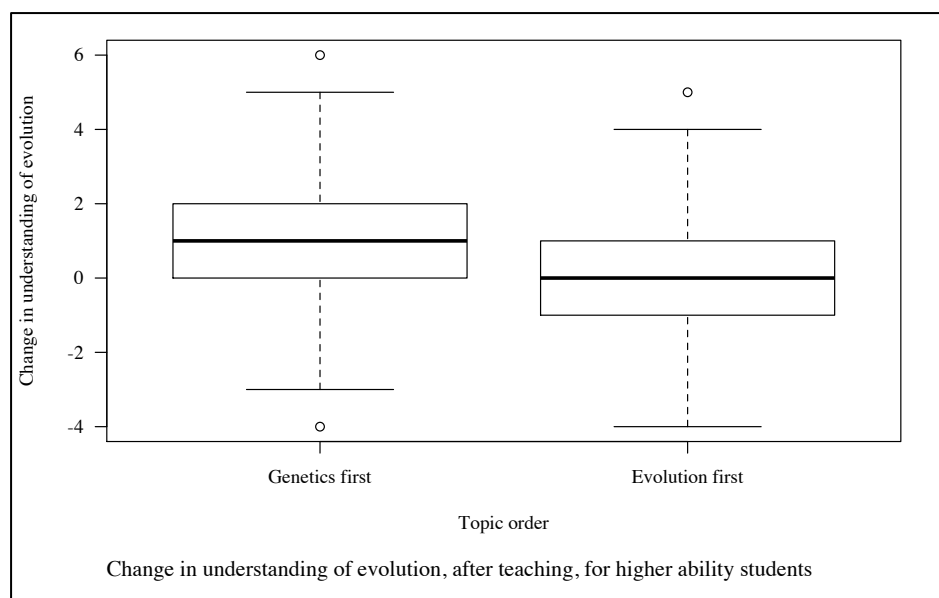


Figure 5.12 Change in understanding of evolution due to teaching for higher ability students taught genetics first (n=685) and evolution (first n=374).

Only lower ability students who were taught genetics first saw a significant increase in evolution understanding (genetics first: $Z = 599$, $p < .001$, evolution first: $Z = 758$, $p = .9$). Those who learnt about genetics first showed a greater increase in understanding compared to those who were taught evolution first ($W = 4471.5$, $p = .03$). This represents an increase of 9%. This is shown in Figure 5.13.

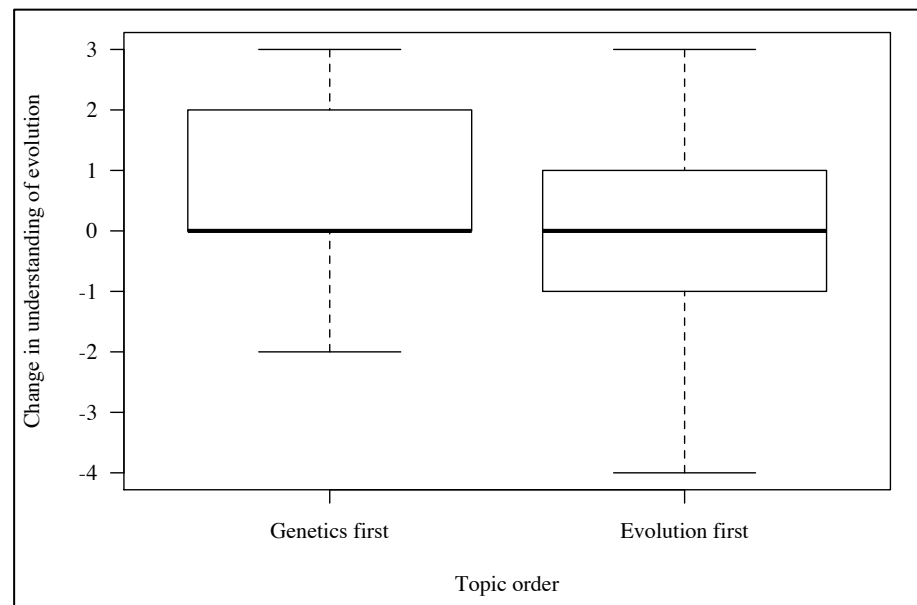


Figure 5.13 Change in understanding of evolution due to teaching for lower ability students taught genetics first ($n=94$) and evolution (first $n=80$).

5.4.2 Teaching genetics first increases genetics knowledge for higher and lower ability students

Higher ability students show a significant increase in genetics understanding regardless of which topic order they are taught first (genetics first: $Z = 45985$, $p < .001$, evolution first: $Z = 15202.5$, $p < .001$). However, the two groups are significantly different before ($W = 263571.5$, $p < .001$) and after ($W = 222113.5$, $p < .001$) teaching. Therefore a linked data approach has been utilised to further investigate these changes. Again, both linked groups show a significant increase in knowledge (genetics first: $Z = 10050$, $p < .001$, evolution first: $Z = 13372$, $p < .001$). There is a significant difference between the two groups after teaching ($W = 91467.5$, $p < .001$) with those who learnt about genetics first having higher post scores than those who were taught evolution first. Those who learn genetics first

also show a greater increase in knowledge than those taught evolution first ($W = 70724.5, p = .002$).

Lower ability students also show a significant increase in genetics understanding regardless of which topic order they are taught first (genetics first: $Z = 1342, p < .001$, evolution first: $Z = 2099.5, p < .001$). The two groups were not significantly different before teaching ($W = 16048.5, p = .97$) but lower ability students who learnt about genetics first demonstrated greater genetics knowledge than those who were taught evolution first ($W = 12162, p = .002$). There was a significant difference between the change in scores with those taught genetics first showing the greater change in knowledge of evolution ($W = 7933.5, p = .03$). The average increase was small at just 1.7 marks, and represents a 5% increase in knowledge of evolution.

5.3.3 Topic order has no impact on evolution acceptance

Higher ability students taught either topic order show a significant increase in evolution acceptance (genetics first: $Z = 47143.5, p < .001$, evolution first: $Z = 14699, p < .001$). The two groups are significantly different before learning about evolution and genetics ($W = 228160, p = .01$) but are similar after teaching ($W = 179555, p = .05$). A linked approach is again used and again finds that both groups show a significant increase in knowledge after teaching (genetics first: $Z = 12390.5, p < .001$, evolution first: $Z = 14552, p < .001$). There is no significant difference between the post teaching scores of the two groups ($W = 91474, p = .06$) nor is there any difference in the amount of change between the two topic orders ($W = 78153, p = .06$).

Similarly, lower ability students show a significant increase in acceptance of evolution, regardless of topic order (genetics first: $Z = 1822, p < .001$, evolution first: $Z = 1370, p < .001$). The two groups are not significantly different before ($W = 14718.5, p = .1$) or after ($W = 10405.5, p = .05$) teaching. There was also no significant difference in the amount of change between the two groups ($W = 6856.5, p = .1$).

In summary, findings from the previous section related to topic order are not due to ability of students. That is to say, teaching genetics first increases understanding of evolution and genetics for both higher and lower ability students. Topic order appears to have no impact on evolution acceptance, regardless of academic ability.

5.5 Relationships between understanding and acceptance

We have already seen that, even before teaching, there is a moderate, positive relationship between evolution acceptance and genetics understanding. Weaker positive relationships are also observed between evolution acceptance and evolution understanding, and between knowledge of genetics and evolution. But what happens to these relationships after students have learnt about genetics and evolution?

Correlations after teaching between evolution acceptance, genetics understanding and evolution understanding all appear similar to those seen prior to teaching. There is significant, moderate positive correlation between acceptance of evolution and knowledge of genetics ($R_s = 0.46, p < .001$), between acceptance of evolution and knowledge of evolution ($R_s = 0.33, p < .001$), and between understanding of evolution and knowledge of genetics ($R_s = 0.47, p < .001$), after teaching. Figures for all three relationships are shown in Figures 5.14, 5.15 and 5.16, and include both pre and post data. Correlations of all pre and post relationships can be found in Table 5.5. Interestingly the correlation between evolution knowledge and genetics knowledge is now the strongest, having previously been the weakest. Partial correlations can be found in Table 5.6 and again show very similar correlations as seen previously: the correlation between evolution acceptance and genetics knowledge, controlling for evolution knowledge, is stronger than that between evolution acceptance and evolution knowledge. (Further discussion of the differences between correlations including comparisons between higher and lower abilities and topic order can be found in the supplementary materials.)

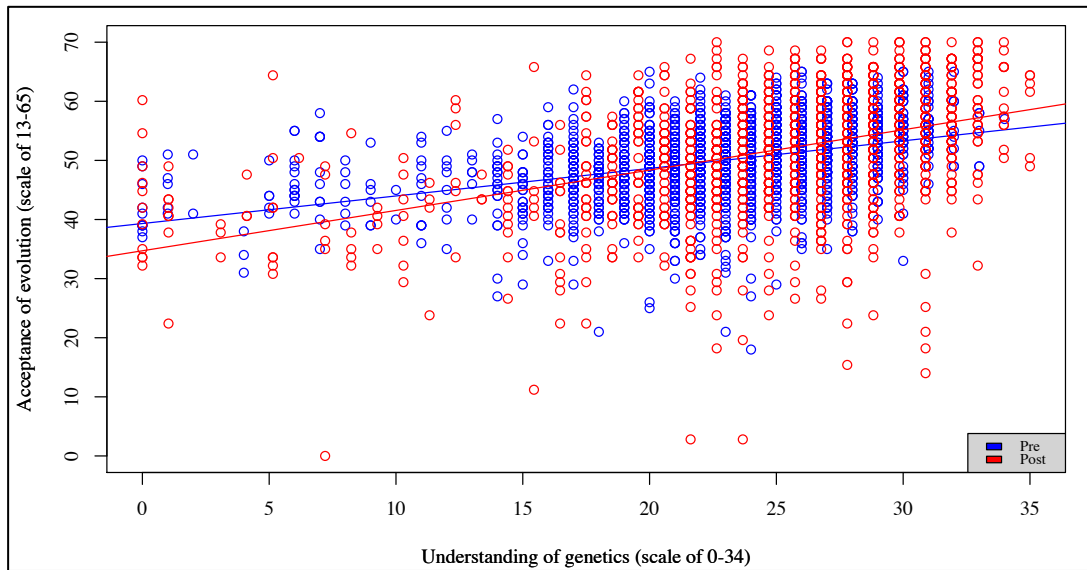


Figure 5.14 Correlation between acceptance of evolution and understanding of genetics, before (N=1717) and after (N=1525) learning about evolution and genetics.

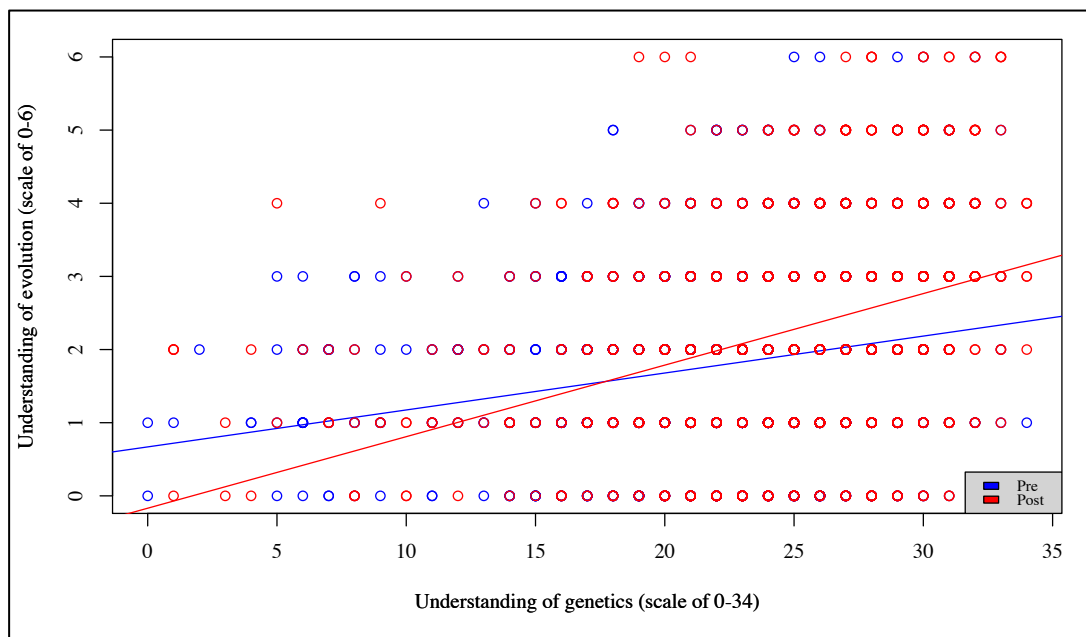


Figure 5.15 Correlation between understanding of evolution and understanding of genetics, before (N=1717) and after (N=1525) learning about evolution and genetics.

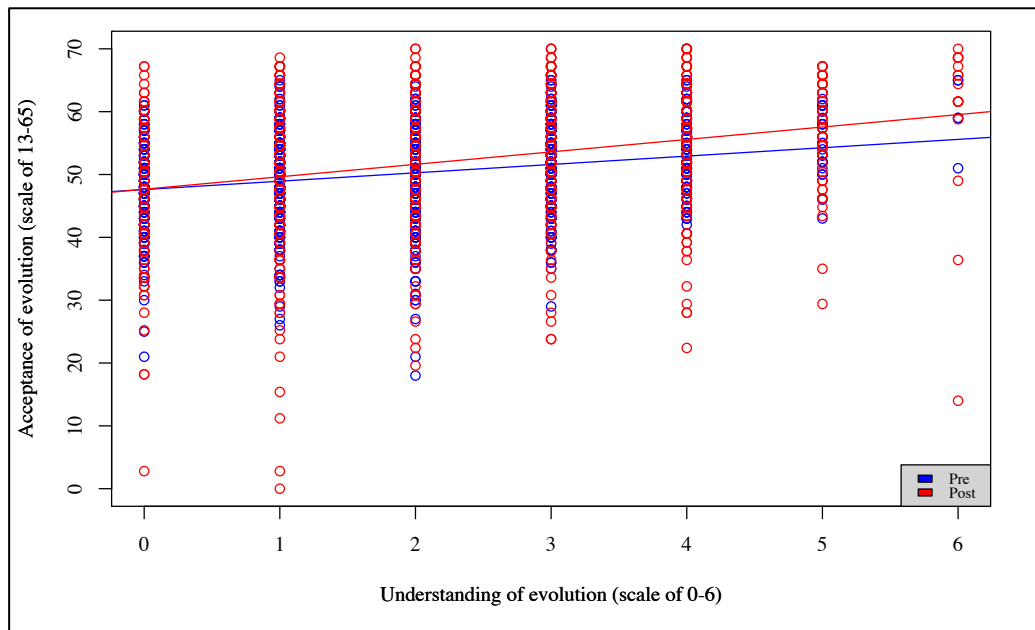


Figure 5.16 Correlation between acceptance of evolution and understanding of evolution, before (N=1717) and after (N=1525) learning about evolution and genetics.

| R_s | Pre | Post |
|--|--------|--------|
| Evolution acceptance and genetics knowledge | 0.4332 | 0.4579 |
| Evolution acceptance and evolution knowledge | 0.2653 | 0.3329 |
| Evolution knowledge and genetics knowledge | 0.2541 | 0.4744 |

Table 5.5 Correlations between evolution acceptance, genetics knowledge, and evolution knowledge. All correlations are highly significant ($p < .001$).

| R_s | Pre | Post |
|--|--------|--------|
| Evolution acceptance and genetics knowledge, given evolution knowledge | 0.3923 | 0.3614 |
| Evolution acceptance and evolution knowledge, given genetics knowledge | 0.1781 | 0.1478 |

Table 5.6 Partial correlations between evolution acceptance and genetics knowledge, controlling for evolution knowledge and evolution acceptance and evolution knowledge, controlling for genetics knowledge. All correlations are highly significant ($p < .001$).

5.6 Summary and implications for teaching

Many of the results in this chapter are reassuring. Teaching has, on average, a positive impact on evolution acceptance and genetics knowledge for around two thirds of students. Perhaps more worrying is that although teaching has a net positive effect on evolution knowledge, this was for just under half of all students. Approximately a quarter of students show negative change for acceptance and understanding of both topics. Overall, these findings should be viewed as a positive outcome for educators. However, concerns must be raised of the students who show little or negative change. What could be done to help these students' understanding of genetics and, in particular, evolution?

Perhaps as might be expected, higher ability students show greater knowledge of evolution and genetics before and after they are taught these topics. It is interesting that ability is also implicated in evolution acceptance, however teachers should be aware that, if the proportions found within this study are representative of the wider student population, they are no more likely to find students who reject evolution in either ability group.

We highlight a particularly striking and potentially important result. Topic order does seem to be important in increasing knowledge of both genetics and evolution. This would suggest that students are able to understand evolution better if they already have an understanding of genetics. The reasons as to why genetics understanding also increases are unclear and worthy of further scrutiny. It does however suggest a simple cost free teaching intervention that now has robust support.

Our analysis also found one apparently contradictory result. Given that there is a positive correlation between evolution and genetics understanding and evolution acceptance, one might reasonably have expected that an increase in evolution and genetics understanding from teaching genetics first would result in a commensurate increase in evolutionary acceptance. Why did we not observe this? One reasonable hypothesis centres on the weakness of the effects concerned. Note that the correlations between understanding and acceptance are not especially

strong. Note too that the degree of increase in genetics and evolution understanding seen in the genetics first class is relatively modest (see Figures 5.9 and 5.11). As the underlying correlation between understanding and acceptance is itself modest, a small increment in understanding (that which was taught) would be diluted to an even smaller increment in acceptance. It may well be that even with our more than respectable sample sizes for this type of intervention, we have no ability to detect such a modest effect. Thus while at first sight a contradictory result, we consider it a better reflection of the perhaps curious modesty of the coupling between understanding and acceptance.

Chapter 6. Retention test results

Here I compare pre, post and retention tests to ask whether teaching makes a lasting difference. I also consider the views and knowledge which students take from their only compulsory education on evolution. Reassuringly we find strong evidence that teaching has a lasting, positive impact on evolution acceptance, genetics knowledge, and evolution knowledge. A high proportion of students accept evolution. Most students have good understanding of genetics, but knowledge of evolution is poor with many students showing misconceptions and ideas that do not agree with scientific understanding of the theory. The relationships between evolution acceptance, evolution knowledge, and genetics knowledge appear similar before and throughout education on these topics.

In the previous chapter we demonstrated that teaching has a positive impact on acceptance and understanding, immediately after students have learnt about evolution and genetics. Within this chapter we investigate what happens after time has lapsed since teaching and ask whether students retain this knowledge and level of acceptance. This is an important consideration: if students show an increase in knowledge immediately after teaching, but then return to their pre teaching level a few months later, it could be argued that education is not successful.

For many students, this may be the last (if not only) time they learn about evolution. The responses found within these retention tests may therefore be representative of students' lasting thoughts and understandings of these topics. (Although it is acknowledged that students have yet to sit their GCSE examinations and presumably there will be some re-learning and revision of these topics for these.) A more descriptive approach is also used to depict the levels of acceptance and understanding that students have when they leave school, and to identify any prevailing misconceptions.

Data used in this chapter are purely a sub section of all data: pre and post data are only included for classes that completed the retention test (and therefore numbers and statistical tests may vary slightly to results reported in Chapters 4 and 5). The

timing of the retention test varied between classes but was generally three to six months after these topics were taught, and did not correspond to any revision or examination of evolution or genetics. Although a smaller cohort, the subsection of students who completed the questionnaire retention test are not significantly different from the larger student sample whose questionnaire results are reported in Chapters 4 and 5 (statistical analyses can be found in the supplementary materials). They also show the same trend of significant increases in acceptance and understanding immediately after teaching, as were seen in students sampled in Chapter 5 (as shall be discussed within this chapter) and are thus thought to be representative of the larger sample. First, the overall impact of teaching is considered.

6.1 The lasting impact of teaching

Teaching has a positive and long-term impact on evolution acceptance, genetics understanding, and evolution understanding. As previously observed, students show significant increase in acceptance and understanding, immediately after learning about evolution and genetics (evolution acceptance: $Z = 8749.5$, $p < .001$; genetics understanding: $Z = 8574.5$, $p < .001$; evolution understanding: $Z = 8269$, $p < .001$). Their evolution acceptance and evolution understanding have not changed significantly by the time of the retention test (evolution acceptance: $Z = 16879$, $p = .63$; evolution understanding: $Z = 7479$; $p = .054$). Genetics understanding is significantly different ($Z = 12560.5$, $p < .048$), however it is still significantly higher than prior to teaching ($Z = 5196.5$, $p < .001$). These are all shown in Figure 6.1. The changes in scores confirm that teaching has a lasting impact and are shown in Figure 6.2. There are significant differences between the pre-post and post-retention tests (evolution acceptance: $Z = 24255.5$, $p < .001$; genetics understanding: $Z = 210055$; $p < .001$; evolution understanding: $Z = 12910.5$, $p = .04$) and between post-retention and pre-retention scores (evolution acceptance: $Z = 5341$, $p < .001$; genetics understanding: $Z = 5618$, $p < .001$; evolution understanding: $Z = 4910$, $p < .001$). There are no significant differences between the pre-post and pre-retention scores (evolution acceptance: $Z = 16111$, $p = 0.4$; genetics understanding: $Z = 11556.5$, $p = .09$; evolution understanding: $Z = 6906$, $p = .1$).

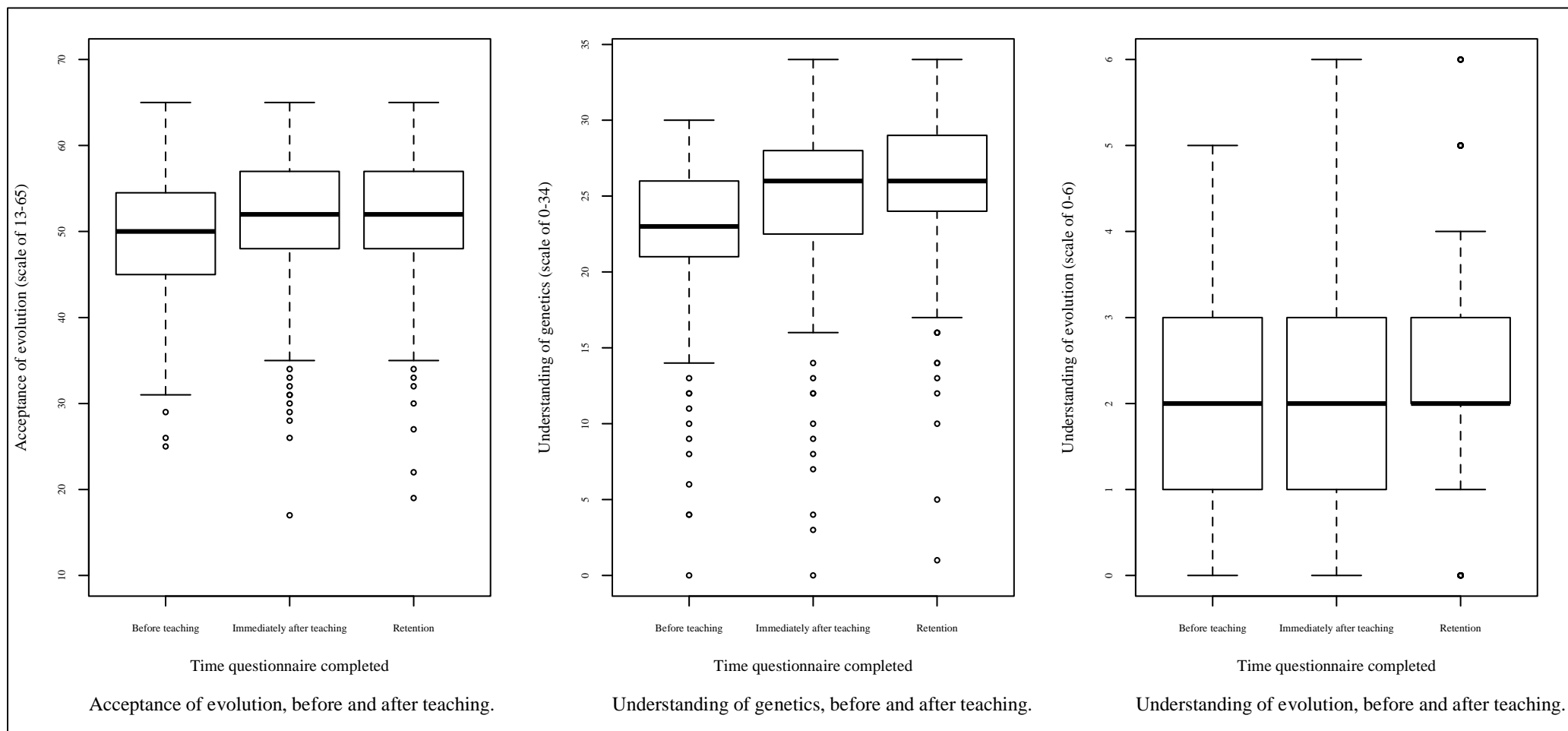


Figure 6.1 Pre, post, and retention test scores for evolution acceptance, genetics knowledge, and evolution knowledge (evolution acceptance: pre n=388, post n=365, retention n=329; genetics knowledge: pre n=388, post n=363, retention n=329; evolution knowledge: pre n=379, post n=346, retention n=310). (Please refer to Figure 4.5 for an explanation of this type of plot.)

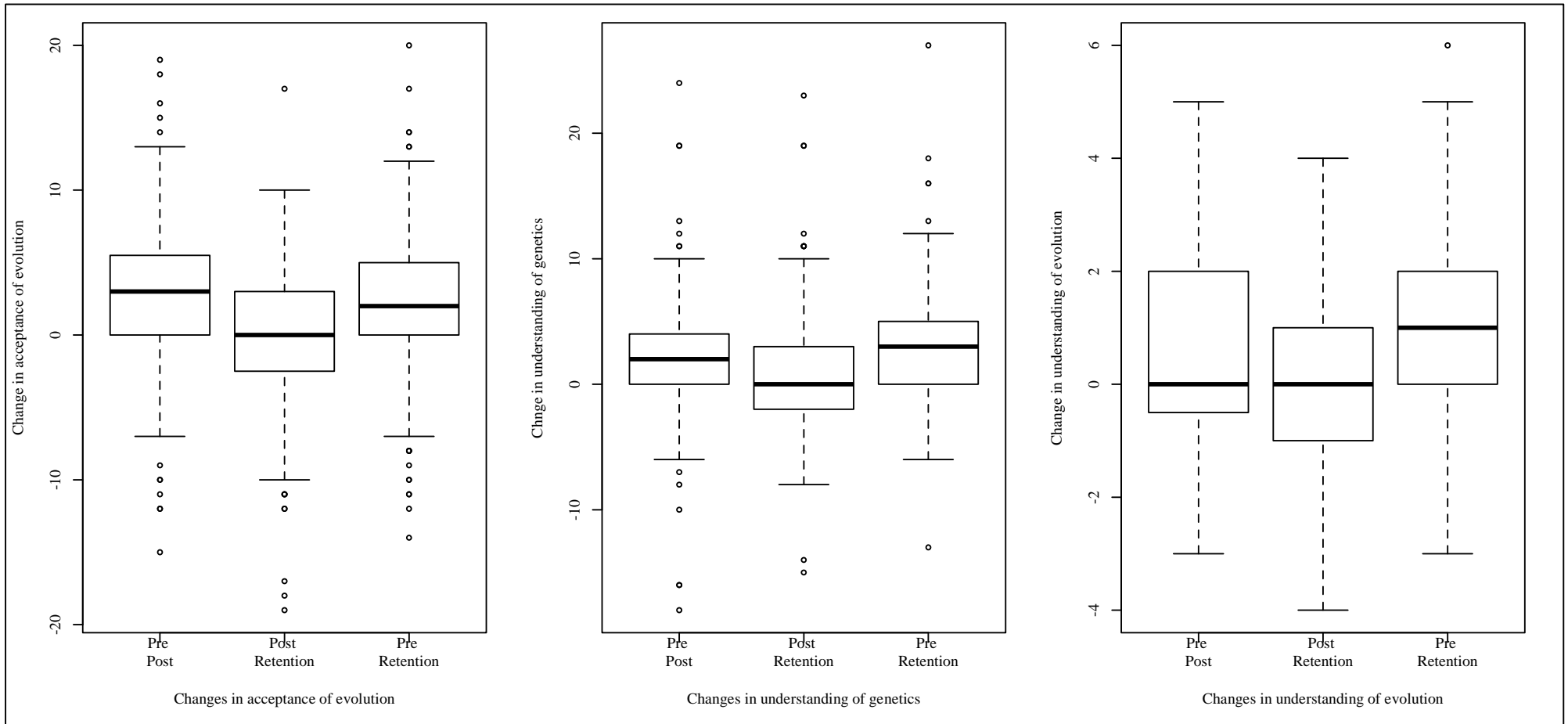


Figure 6.2 Changes in pre, post, and retention test scores for evolution acceptance, genetics knowledge, and evolution knowledge (evolution acceptance: pre-post n=339, post–retention n=280, pre-retention n=297; genetics knowledge: pre-post n=337, post-retention n=278, pre-retention n=297; evolution knowledge: pre-post n=319, post-retention n=258, pre-retention n=280).

6.1.1 Teaching has a lasting impact on evolution acceptance

Here we consider changes in acceptance of evolution over the duration of this study. The overall proportions of students who accept evolution at the times of the three questionnaires are displayed in Figure 6.3 (these are slightly different to previously observed proportion in Chapters 4 and 5 due to this being a sub sample of those data). 84% of students demonstrate an acceptance of evolution in the retention test. This is the same percentage as immediately after teaching. 15% of students are undecided. There is little variation in the proportion of students who reject evolution.

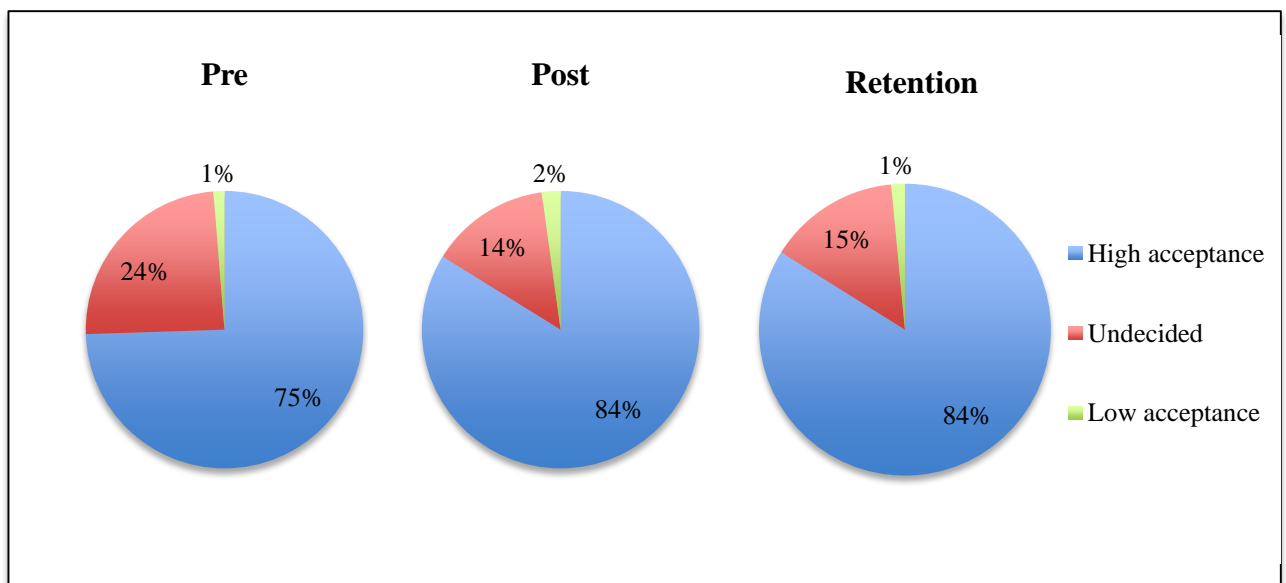


Figure 6.3 Overall student acceptance of evolution at the three questionnaire times (pre n=388, post n=365, retention n=329).

The changes between the different categorisations of acceptance are shown in Figure 6.4 (based on the acceptance categories described in Table 4.1). The largest group by far is consistently the high acceptance category and varies by only 2%. Low acceptance categories also retain similar proportions throughout. The main variations appear in the undecided and very high acceptance categories. There is a large decrease in the proportion of students who were undecided before teaching, and an increase in the proportion of students who show very high acceptance after teaching. There is only very slight reversal of these trends between the post and retention tests with a small increase in the proportion of

students who are undecided and a decrease of 2% in the students who are highly accepting of evolution. Overall this confirms the previously identified trend towards higher evolution acceptance, but suggests a minor long-term reversal among a very small proportion of students.

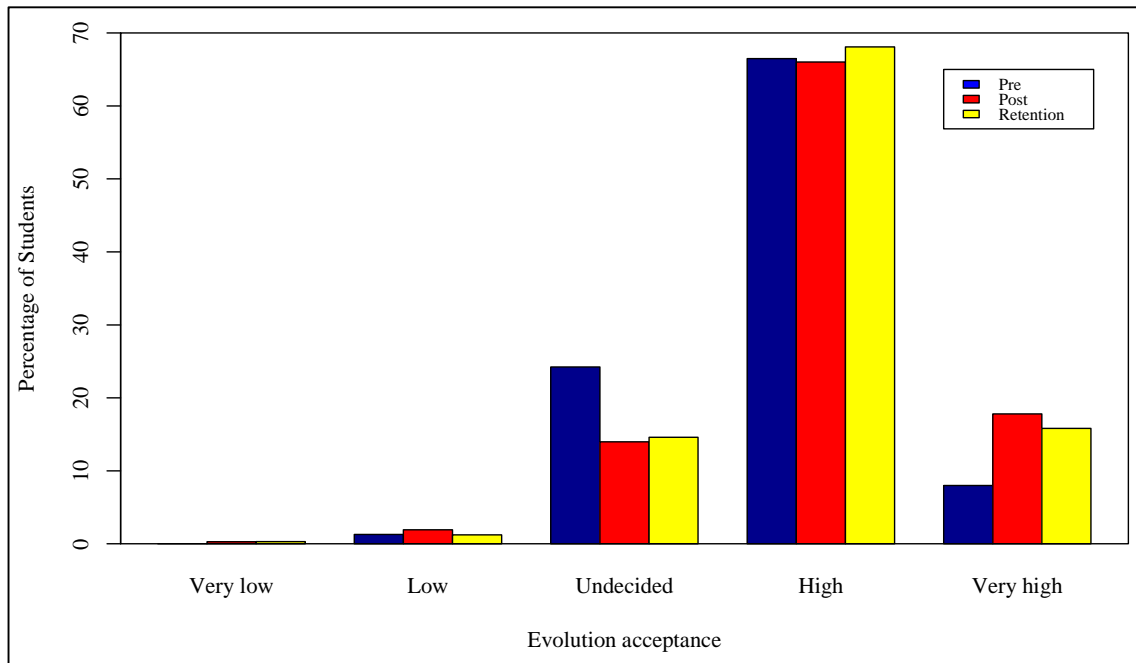


Figure 6.4 Student acceptance of evolution at the three questionnaire times, using categorisations based on the five potential answers to each questionnaire item (pre n=388, post n=365, retention n=329).

These changes are further explored in Figures 6.5 to 6.7. Figure 6.5 shows how students' acceptance changes between their pre and post questionnaires and is similar to the changes discussed in Chapter 5. The majority of students who accept evolution prior to teaching, still show acceptance after teaching and many students who were previously undecided are now accepting. There is some variation among students who previously rejected evolution, but most remain unaccepting.

What are of particular interest are the changes seen by the time of the retention test. There is some movement among categorisations between the post and retention test (Figure 6.6). Over 50% of students who showed very high or high acceptance, or were undecided, immediately after teaching, remain within the

same category. This suggests that the impacts of teaching are long lasting. There is some fluctuation between the high and very high categories, and 9% of those who previously accepted evolution are now undecided. 50% of those students who displayed low acceptance immediately after teaching are now undecided. The reasons for these changes are unknown, and given the relatively small sample size, particularly for low acceptance, this may represent little more than random variation, as discussed Figure 5.3.

The changes between pre and retention test are shown in Figure 6.7. This demonstrates how longer-term acceptance changes relative to acceptance prior to teaching. The overall pattern is very similar to that seen between pre and post scores (Figure 6.5) and again suggests that teaching does have a lasting impact for students. The most notable difference is the proportion of previously unaccepting students who are now undecided about evolution (40%). No students show longstanding very low acceptance of evolution.

Overall, these figures reflect the positive impact that teaching has on students, particularly those who were previously undecided about evolution, and that this effect is long lasting. It is harder to make judgements about those students who were already accepting of evolution: teaching does not appear to effect them negatively, yet the majority of students who show high acceptance prior to teaching do not display very high acceptance after education, as might be expected. For those students who are very highly accepting, something of a ceiling effect is observed whereby students are unable to increase their acceptance. Comparing these findings with those in Figure 6.1 reveal that although teaching does have a net positive effect on evolution acceptance, this is a relatively small impact for most students, but it is long lasting.

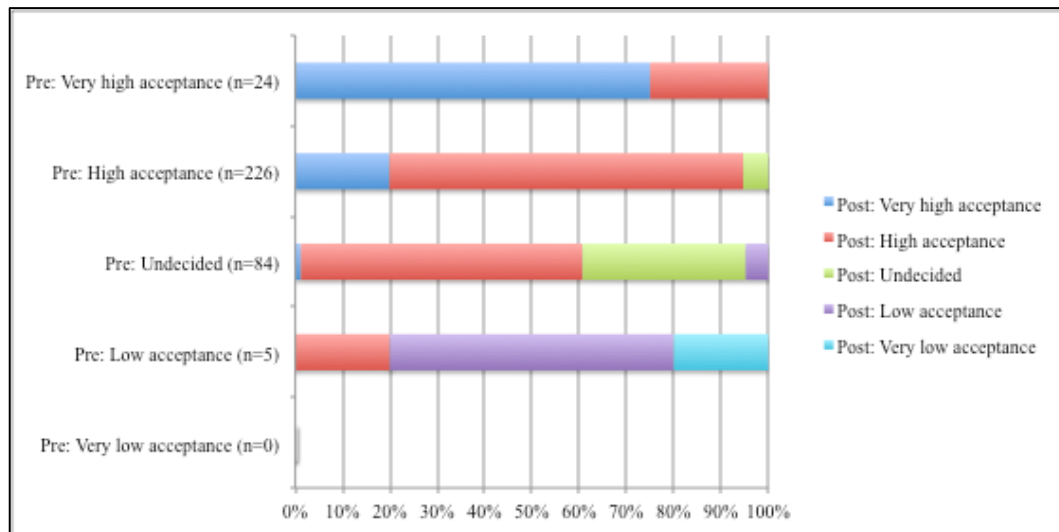


Figure 6.5 Change in evolution acceptance category between pre and post tests (n=339).

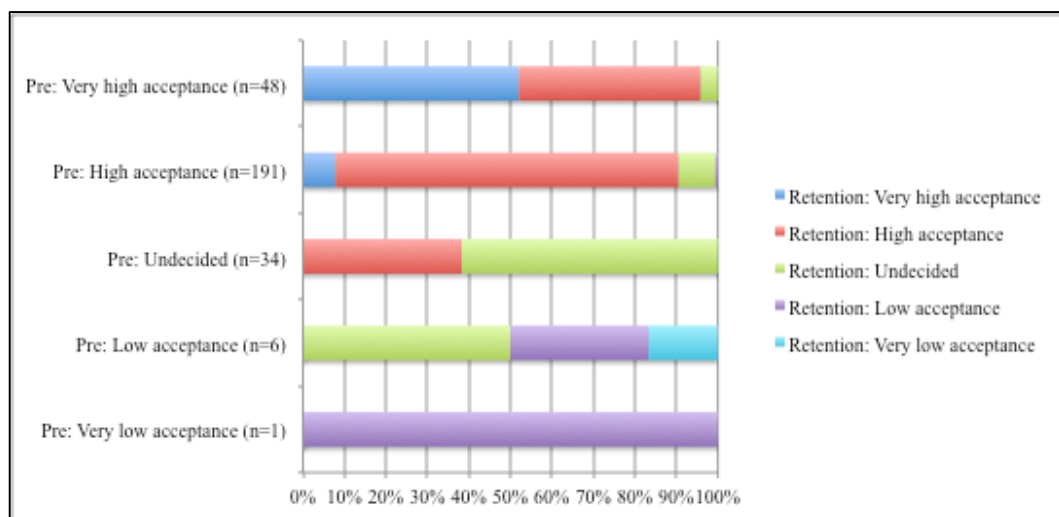


Figure 6.6 Change in evolution acceptance category between post and retention tests (n=280).

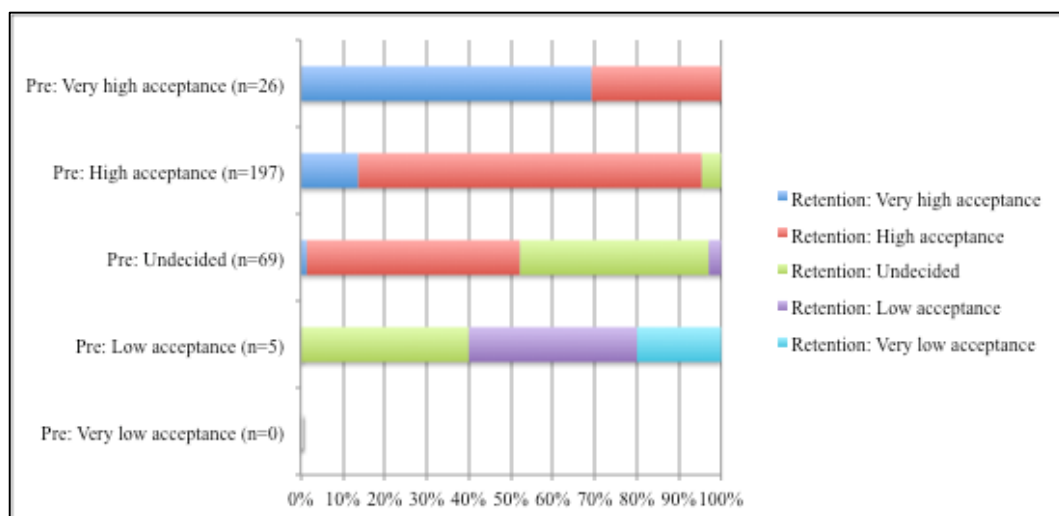


Figure 6.7 Change in evolution acceptance category between pre and retention tests (n=297).

6.1.1.1 Students accept different aspects of evolution

There are small differences between individual evolution acceptance items and aspects of evolution. The proportions of acceptance for each of the seven aspects are shown in Figure 6.8. There is an increase in the proportion of students who accept each aspect, compared to those found prior to teaching (Figure 4.3) and these retention acceptance scores are similar to those seen in the post test (Figure 5.4). Overall the same trends remain with evolution as an explanation for modern life, human evolution, and evidence for evolution being the most accepted aspects (83%, 82% and 82% respectively). The validity of evolution has the lowest proportion of acceptance (59%) and the highest level of indecision (35%). Dinosaurs and humans show the highest proportion of non-acceptance (11%), followed by 9% of students who reject human evolution. With the exception of these two aspects, there is little variation in the proportions of non-acceptance: evidence for evolution, testability, and geological time, have the lowest proportion of rejection, each with 5%. (Further information on this can be found in the supplementary materials.)

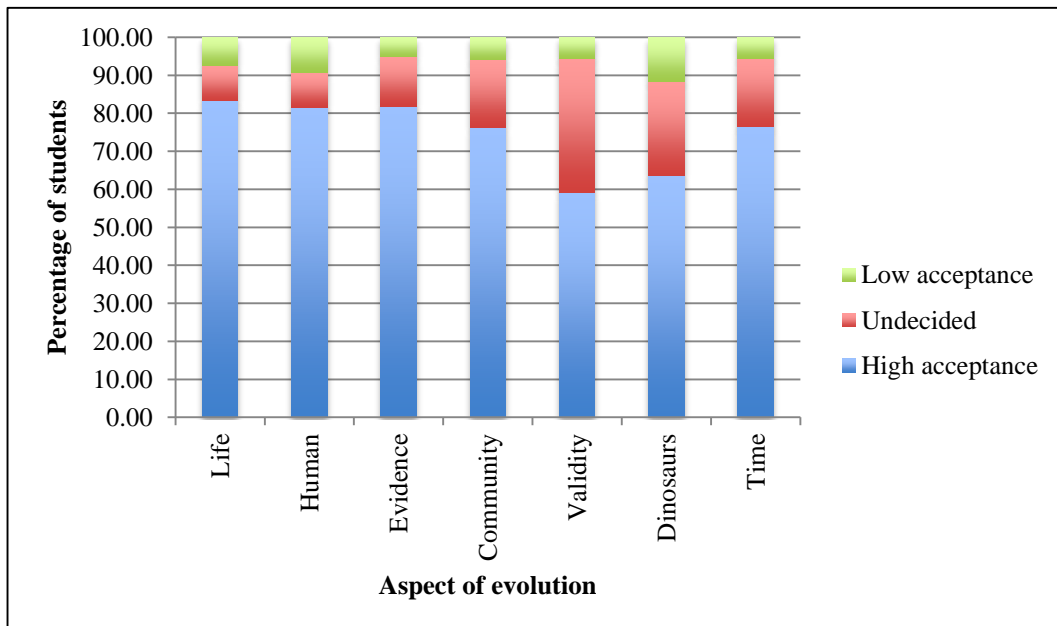


Figure 6.8 Acceptance of different aspects of evolution, three to six months after teaching (N=329).

6.1.2 Teaching has a lasting impact on genetics knowledge but misconceptions persist

As shown in Figure 6.1 and 6.2, education has a lasting positive effect on genetics knowledge. Most students complete their compulsory education with knowledge of genetics which remains at least three to six months after teaching. The frequency of correct answers found in the retention test is shown in Figure 6.9. The average score is 26 which represents 76% of questions answered correctly.

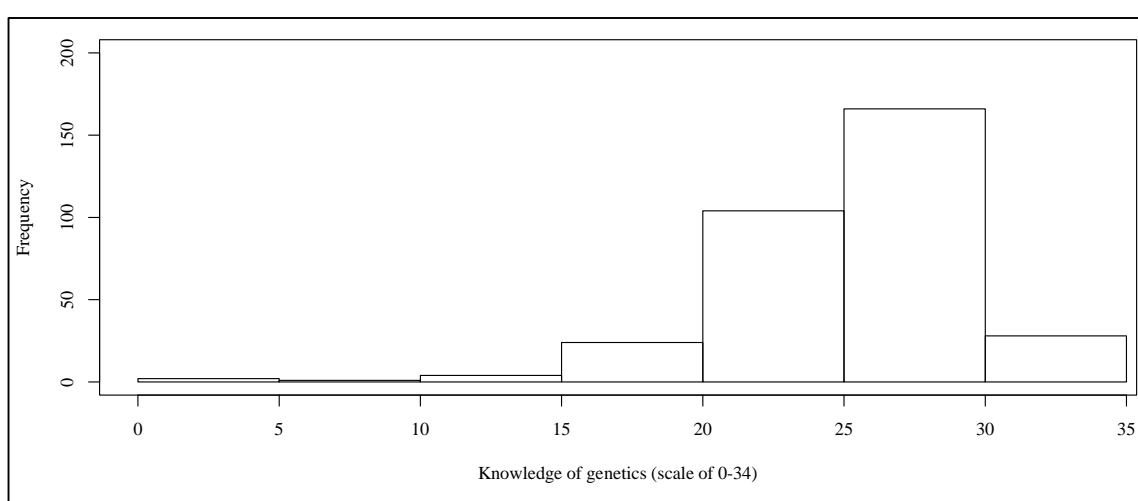


Figure 6.9 Knowledge of genetics, three to six months after teaching (N=329).

There is still much variation between students' responses to individual questions and despite the positive impact teaching has been shown to have, there are still numerous areas of confusion. Findings are summarised in Table 6.1. The proportion of students present who gave the correct answer is given, along with a classification of knowledge, as utilised in Chapter 4 and as described in Table 4.2. Alternative answers are also highlighted.

Students have 'good' knowledge of 56% of the questions and only 'poor' knowledge of one question. As found prior to teaching, students generally have good knowledge of the 'living organisms' questions (Q16). The vast majority of students are able to classify mammals, insects, and plants correctly and know that they contain genetic information. However, 17% of students do not consider humans to be animals. Students still struggle with bacteria and viruses. Given the

importance of topics such as antibiotic resistance and inclusion of these in GCSE syllabi, this is somewhat concerning and suggests students fail to understand key ideas related to these topics.

Perhaps unsurprisingly, knowledge of key terminology has increased since teaching, with knowledge of most terms now being 'good' (Q17). However, only 63% of students are able to correctly define genetic variation with some confusion over environmental variation and other terms. This is worrying given that this a core concept, typically taught at the start of genetics topics, and often introduced at a younger academic stage. Less than 50% of students still seem unaware of what "alleles" are. This term is not included in all foundation GCSE exam syllabi which might explain some but not all of this lack of knowledge. Nearly three quarters of students had knowledge of genetic engineering (Q20) although there was confusion with cloning for 12% of students.

It is concerning that 65% of students are still unable to correctly identify the sequential relationship between structures in the 'size sequence' question (Q15). Confusion between genes and chromosomes persist, with 30% of students selecting genes as being larger than chromosomes. Plant reproduction (Q19) is clearly still an area of confusion, with over 50% of students thinking that plants reproduce asexually only. Given that students will have covered basic Mendelian inheritance and are likely to have used plants as key examples for genetic crosses, this is concerning. The most difficult question was the same as prior to teaching and related to cell function (Q18): only 19% of students correctly identified that different types of cells have different functions because they activate different genes. 43% thought different types of cells contained different kinds of genes.

| Question | Area | Correct (%) | Knowledge | Alternative answer (s) |
|----------|-------------------------------|-------------|-----------|---|
| Q16h | Animals: giraffes | 99.39 | Good | Giraffes are not animals |
| Q16s | Genetic information: humans | 99.09 | Good | Humans do not contain genetic information |
| Q16t | Genetic information: giraffes | 98.48 | Good | Giraffes do not contain genetic information |
| Q16a | Living organisms: humans | 97.57 | Good | Humans are not living organisms |
| Q16b | Living organisms: giraffes | 96.96 | Good | Giraffes are not living organisms |
| Q16a | Living organisms: moths | 96.96 | Good | Moths are not living organisms |
| Q16m | Cells: humans | 96.96 | Good | Humans are not made up of cells |
| Q16o | Cells: moths | 96.96 | Good | Moths are not made up of cells |
| Q16u | Genetic information: moths | 96.96 | Good | Moths do not contain genetic information |
| Q16n | Cells: giraffes | 96.05 | Good | Giraffes are not made up of cells |
| Q17e | Asexual | 92.40 | Good | Definition/meaning of word |
| Q16d | Living organisms: oak tree | 91.79 | Good | Oak trees are no living organisms |
| Q17c | Clone | 88.75 | Good | Definition/meaning of word |
| Q16e | Living organisms: bacteria | 86.63 | Good | Bacteria are not living organisms |
| Q16p | Cells: oak tree | 86.32 | Good | Oak trees are not made of cells |
| Q16g | Animals: humans | 83.28 | Good | Humans are not animals |
| Q16i | Animals: moths | 83.28 | Good | Moths are not animals |
| Q16v | Genetic information: oak tree | 79.94 | Good | Oak trees do not contain genetic information |
| Q17d | Gamete | 78.42 | Good | Definition/meaning of word |
| Q16j | Animals: oak tree | 74.77 | Medium | Oak trees are animals |
| Q16l | Animals: virus | 73.86 | Medium | Viruses are animals |
| Q16k | Animals: bacteria | 73.56 | Medium | Bacteria are animals |
| Q20 | Genetic engineering | 73.25 | Medium | Confusion between genetic engineering and cloning |

| Question (cont.) | Area | Correct (%) | Knowledge | Alternative answer (s) |
|-------------------------|-------------------------------|--------------------|------------------|---|
| Q17b | Mutation | 69.91 | Medium | Definition/meaning of word |
| Q16w | Genetic information: bacteria | 68.39 | Medium | Bacteria do not contain genetic information |
| Q16q | Cells: bacteria | 67.48 | Medium | Bacteria are not made of cells |
| Q17f | Genetic variation | 63.22 | Medium | Definition/meaning of word |
| Q16x | Genetic information: virus | 52.58 | Medium | Viruses do not contain genetic information |
| Q17a | Alleles | 44.38 | Medium | Definition/meaning of word |
| Q16f | Living organisms: virus | 39.51 | Medium | Viruses are living organisms |
| Q19 | Plant reproduction | 35.87 | Medium | Plants reproduce asexually |
| Q15 | Size sequence | 35.26 | Medium | Confusion of relationship between chromosomes and genes |
| Q16r | Cells: virus | 34.04 | Medium | Viruses are not made of cells |
| Q18 | Cell function | 18.84 | Poor | Different types of cells contain different kinds of genes |

Table 6.1 Genetics knowledge three-six months after teaching (N=329). Knowledge is classified as ‘good’ where over 75% of students answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. It should also be noted that questions 18, 19 and 20 are multiple choice questions with four possible answers. The probability of getting the right answer by chance is therefore 25%. The remaining questions are variations on the multiple choice question but have varying numbers or combinations of possible answers.

6.1.3 Teaching has a lasting impact on evolution knowledge but misconceptions persist

As shown in Figures 6.1 and 6.2, teaching also has a small but positive, long-term impact on evolution knowledge. Most students complete their compulsory (and what might be their only) evolution education with some knowledge of evolution. This remains for at least three to six months after teaching. The frequency of correct answers found in the retention test is shown in Figure 6.10. The mean score is 2.5 which represents 42% of questions answered correctly.

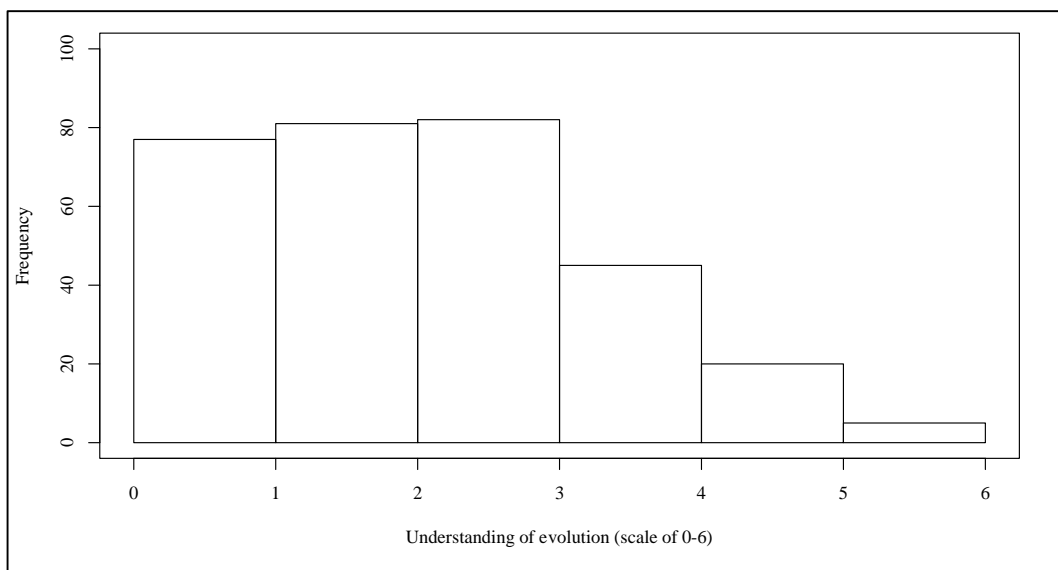


Figure 6.10 Knowledge of evolution, three to six months after teaching (N=329).

There is still much variation between students' responses to individual questions and despite the positive impact of teaching, there are many misconceptions that prevail. Findings are summarised in Table 6.2. As in Chapter 4, the proportion of correct answers is given, along with a classification of knowledge and alternative answers. All questions show an increased proportion of correct answers, compared to post tests.

| Question | Area | Correct (%) | Knowledge | Alternative answer(s) |
|----------|-------------------------|-------------|-----------|---|
| Q24 | Natural selection | 57.45 | Medium | Inheritance of acquired characteristics |
| Q23 | Human evolution | 54.41 | Medium | Humans have evolved from apes |
| Q26 | Geological time | 40.12 | Medium | Lack of knowledge of geological time |
| Q25 | Mechanisms of evolution | 31.91 | Medium | Inheritance of acquired characteristics |
| Q22 | Natural selection | 31.00 | Medium | Lack of knowledge of differential reproduction |
| Q21 | Definition | 20.97 | Low | Development of characteristics in response to need; Change of simple to complex organisms |

Table 6.2 Evolution knowledge three-six months after teaching (N=329). Knowledge is classified as ‘good’ where over 75% of students answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. All questions are multiple choice with four possible answers. The probability of getting the right answer by chance is therefore 25%.

No question knowledge is categorised as ‘good’. Of those questions for which knowledge is designated as ‘medium’, there are a wide variety of responses. Over half of all students now recognise that apes and humans have evolved from a common ancestor (Q23), but other answers are still common. 40% of students have some knowledge of geological time but there is still clear confusion among many students (Q26).

Peppered moths are commonly used in secondary schools as an example of natural selection, therefore it is not surprising that the question relating to this has the highest proportion of correct answers (Q24); however 23% of students still choose the distractor answer of inheritance of acquired characteristics. This misconception is even more evidence when students are asked what natural selection is (Q25): 43% choose inheritance of acquired characteristics as their answer. There is confusion over the conditions necessary for natural selection (Q22) with 33% of students displaying misunderstanding over differential

reproduction, and 17% do not recognise that there is variation among individuals of the same species. 44% of students describe evolution as the development of characteristics in response to need whereas only 21% recognise that evolution is best described as genetic changes in populations and a further 21% consider evolution to involve the development of simple to complex organisms (Q21). These findings are troubling and suggest that students' understanding of evolution does not correspond with that of the scientific community.

To summarise, the significant increases that students show in acceptance and understanding immediately after learning about evolution and genetics continue for at least three to six months after teaching. Most students complete their compulsory education with high acceptance of evolution. Despite some concerning misconceptions, most students have good knowledge of genetics, but know less about evolution.

6.2 Ability and topic order

In Chapters 4 and 5 we demonstrated that ability and topic order play an important part in students' acceptance and understanding of evolution. Here we ask whether these also have a longer-term impact. Unfortunately the smaller size and composition of students who completed the retention test has meant that detailed analysis into all of these important variables has not been possible: only two lower ability classes completed the retention test which, due to high numbers of absences, provided a sample of just 15 students for pre and retention tests and 13 students for post test. Therefore, any analyses involving these students can only be interpreted sceptically. This has also meant that, where different sub samples show different scores before teaching, linked data approaches are not always possible. Despite these difficulties, data have been analysed and findings are outlined here.

6.2.1 Teaching has a lasting impact on students of different abilities

Teaching has a lasting impact on higher ability students' acceptance of evolution, understanding of genetics, and understanding of evolution. Results for higher ability students follow the same pattern observed overall within this chapter:

significant increases in evolution acceptance and genetics and evolution understanding are observed between the pre and post tests (evolution acceptance: $Z = 7871$, $p < .001$; genetics understanding: $Z = 8422$, $p < .001$; evolution understanding: $Z = 7774$, $p < .001$). There is no significant difference in scores for evolution acceptance and evolution understanding between the post and retention tests (evolution acceptance: $Z = 16411$, $p = .6$; evolution understanding: $Z = 7479$, $p = .05$). There is a significant difference between post and retention scores for genetics understanding ($Z = 11904$, $p < .03$) but there is significant difference between the pre and retention scores ($Z = 4974$, $p < .001$), suggesting knowledge of genetics is still greater than prior to teaching. Overall, teaching does have a lasting, positive impact on higher ability students for evolution acceptance, genetics understanding and evolution understanding. These findings are shown in Figures 6.11 to 6.13.

Also shown in Figures 6.11 to 6.13 are lower ability acceptance and understanding scores. In accordance with the trends seen previously, there is a significant difference between pre and post genetics knowledge ($Z = 0$, $p = .006$) and no significant change between post and retention knowledge ($Z = 8.5$, $p = .3$) suggesting that teaching does have a positive and lasting impact on lower ability students' understanding of genetics. However, given the small sample size ($n=15$) this finding should be interpreted tentatively. There were no significant changes observed between pre and post test scores for lower ability students' evolution acceptance and evolution knowledge (evolution acceptance: $Z = 24$, $p = .9$; evolution understanding: $Z = 9$, $p = .4$). Nor were there any significant differences between post and retention acceptance (evolution acceptance: $Z = 4$, $p = .9$; evolution understanding: values too small to run analysis) or pre and retention (evolution acceptance: $Z = 9$, $p = .8$; evolution understanding: $Z = 0$, $p < .4$) scores. However this is likely to be due to the very low sample sizes, so no conclusions can be made about lower ability students' acceptance and knowledge of evolution.

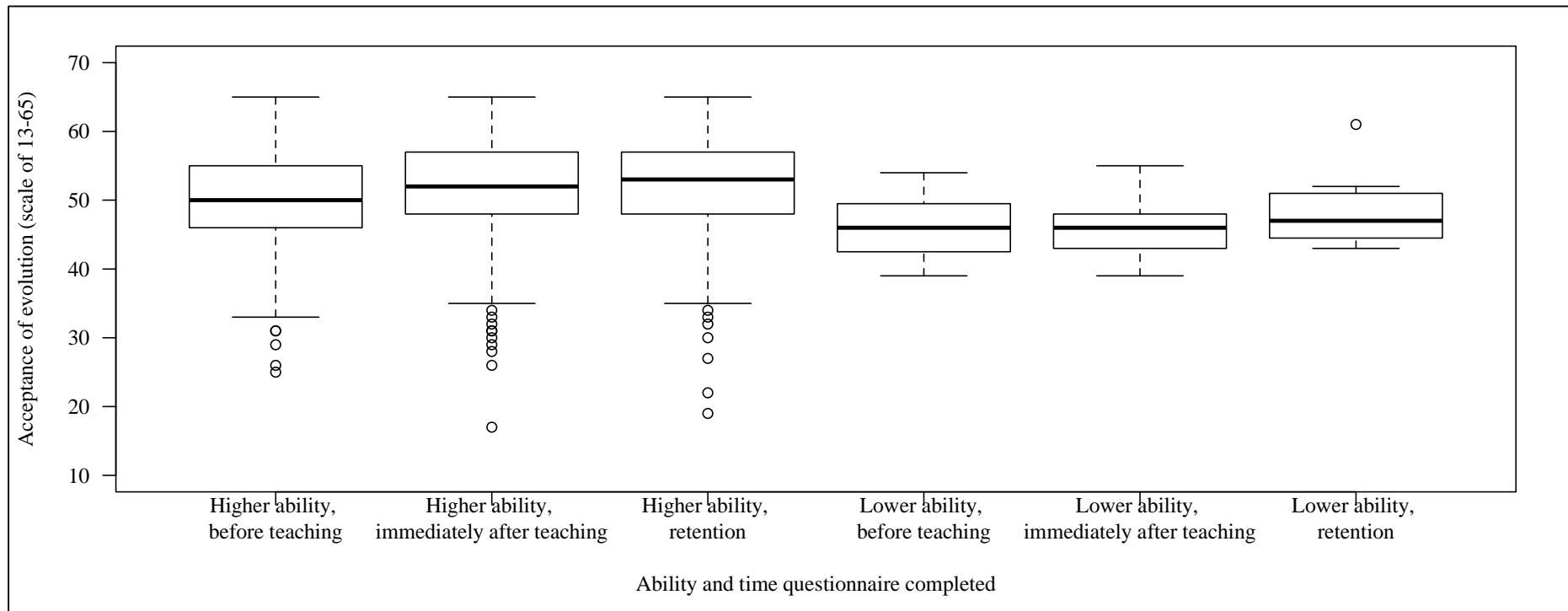


Figure 6.11 Evolution acceptance for higher and lower ability students at the three questionnaire times. Higher ability students have higher acceptance than lower ability students before ($W = 3846$, $p = .01$) immediately after ($W = 3579$, $p < .001$) and three-six months after ($W = 3371.5$, $p = .005$) teaching. (Higher: pre $n=373$, post $n=352$, retention $n=314$; lower pre $n=15$, post $n=13$, retention $n=15$.)

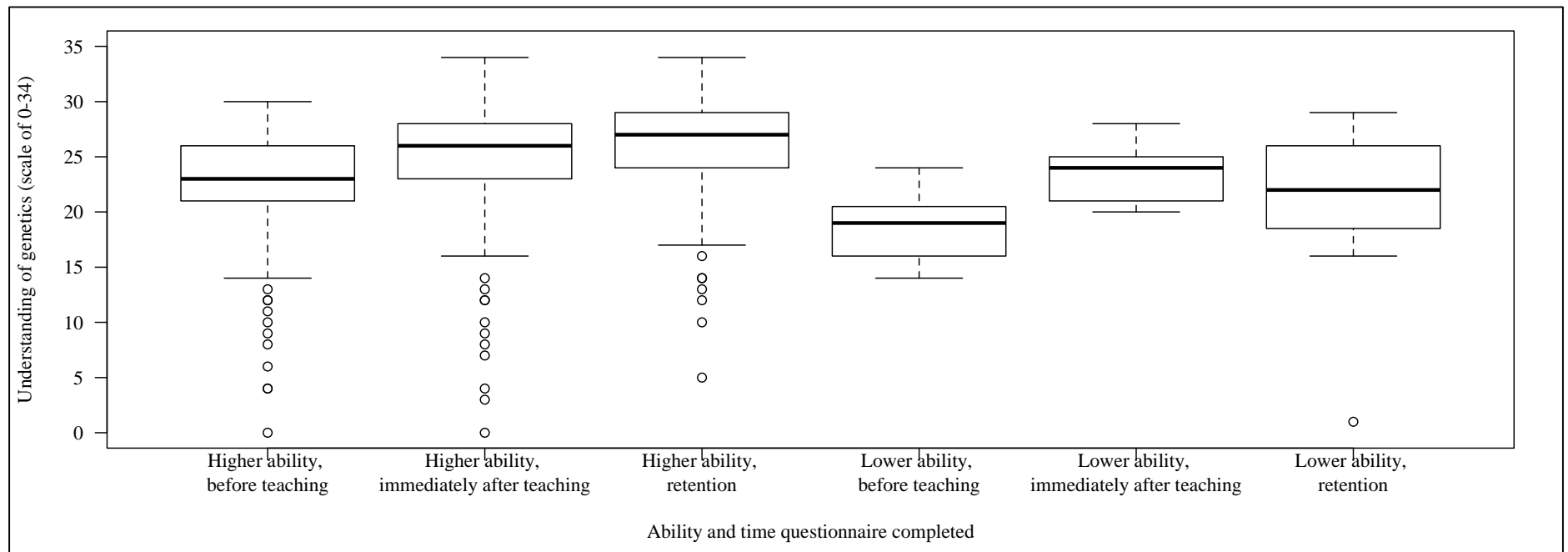


Figure 6.12 Genetics knowledge for higher and lower ability students at the three questionnaire times. Higher ability students have higher acceptance than lower ability students before ($W = 4625.5, p < .001$) and three-six months after ($W = 3513.5, p = .001$) teaching. Post knowledge was not significantly different between higher and lower abilities ($W = 2990, p = .054$). The very low number of lower ability students who completed the post test should be considered when interpreting this result. (Higher pre $n=373$, post $n=350$, retention $n=314$; lower pre $n=15$, post $n=13$, retention $n=15$.)

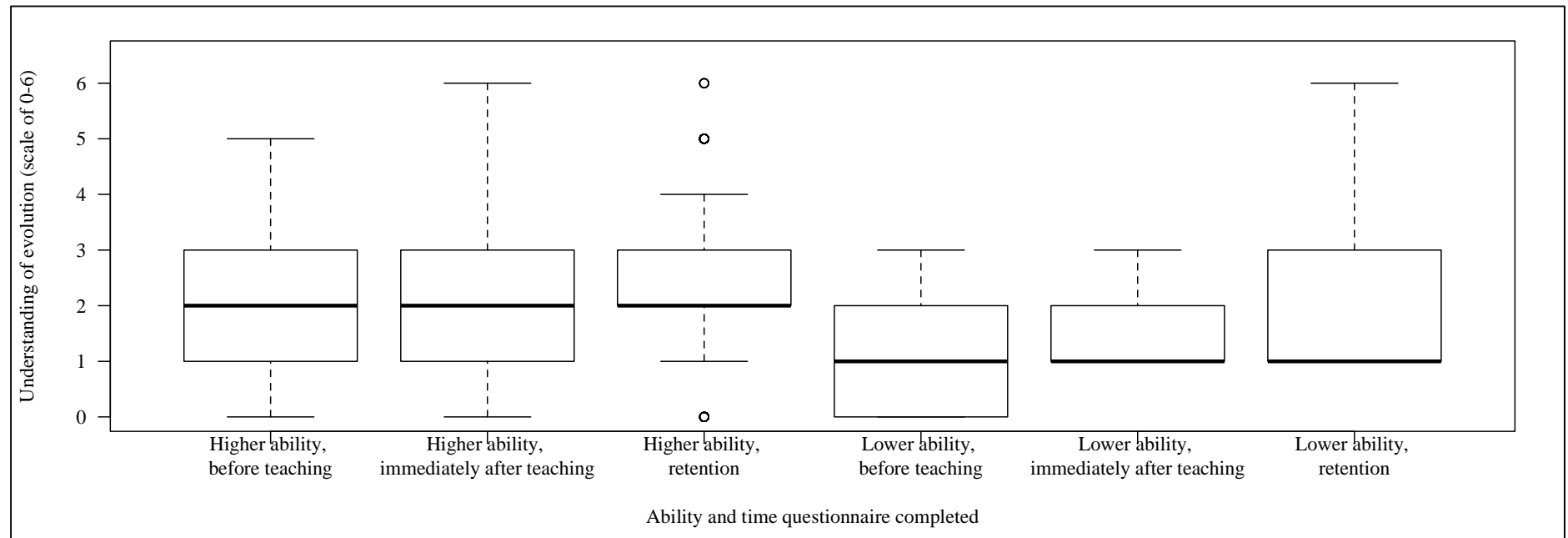


Figure 6.13 Evolution knowledge for higher and lower ability students at the three questionnaire times. Higher ability students have higher acceptance than lower ability students before ($W = 3325$, $p = .048$.) and immediately after ($W = 2993.5$, $p < .002$) teaching. There is no significant difference between retention test scores ($W = 1143.5$, $p = .03$) teaching but the low number sample size means that statistical analysis is not appropriate here. (Higher pre $n=365$, post $n=333$, retention $n=304$; lower pre $n=14$, post $n=13$, retention $n=6$.)

As seen in Chapters 4 and 5, higher ability students have significantly higher scores than lower ability students at nearly all stages at which the questionnaire was administered, and any non-significant results are likely to be heavily influenced by the small sample size. (All statistical analyses are detailed within the descriptions of Figures 6.11 to 6.13.) However, given the small number of lower ability students sampled, further comparisons between the two ability groups (e.g. using the linked data approach) have not been investigated. We conclude that education has a positive and lasting impact on higher ability students' acceptance and understanding, and tentatively suggest that education has a positive, longer-term effect on lower ability students' understanding of genetics but do not have the data to make inferences about evolution acceptance and understanding.

6.2.2 Topic order

Teaching has a positive and longer-term impact on students taught both topic orders. Following the previously identified trend, significant increases in acceptance and understanding were found between pre and post test for students taught genetics first (evolution acceptance: $Z = 3745.5$, $p < .001$; genetics understanding: $Z = 3449.5$, $p < .001$; evolution understanding: $Z = 2362.5$, $p < .001$) and for those taught evolution first (evolution acceptance: $Z = 973.5$, $p < .001$; genetics understanding: $Z = 1122.5$, $p < .001$; evolution understanding: $Z = 1800$, $p = .03$). There were no significant differences between evolution acceptance and evolution understanding post and retention tests for students who were taught genetics first (evolution acceptance: $Z = 4965$, $p = .4$; evolution understanding: $Z = 2375.5$, $p = .3$). There was a significant difference in genetics understanding ($Z = 3368$, $p = .003$); however this was an additional increase in knowledge, and was significantly higher than the score prior to teaching ($Z = 1612$, $p < .001$). There were no significant differences between evolution acceptance, genetics understanding, or evolution understanding post and retention tests for students who were taught evolution first (evolution acceptance: $Z = 3556.5$, $p = .06$; genetics understanding: $Z = 2873$, $p = .8$; evolution understanding: $Z = 1440$, $p = .08$). These results suggest that teaching has a lasting impact, regardless of topic order.

There were no significant differences between the two teaching order groups at any point for evolution acceptance (pre: $W = 17984$, $p = .90$; post: $W = 14158.5$; $p = .09$; retention: $W = 13272.5$, $p = .81$) or for evolution knowledge (pre: $W = 15591.5$, $p = .12$; post: $W = 15583$; $p = .21$; retention: $W = 11636$, $p = .96$). However, the genetics knowledge of the two groups were significantly different before teaching ($W = 20103$, $p = .04$) and at the point of the retention test ($W = 15060.5$, $p = .02$). Further analysis into the changes between questionnaire points and using the linked data approach did not reveal any further information about topic order. Further details on this can be found in the supplementary materials.

It is likely that relatively small sample sizes may have an impact on all the results discussed here. These are more susceptible to class or teacher effects. Why the additional increase in genetics knowledge for those students who were taught genetics first? Could this be related to learning about other topics within biology that include mention of cells or genes? For example, topics such as antibiotic resistance are typically covered in different modules from those dedicated to *genetics* or *evolution*. It seems unlikely that this increase can be attributed to topic order. Given the relatively small sample size, it is most likely this is due to other variables.

6.3 Relationships between acceptance and understanding

Significant positive relationships are found between evolution acceptance and genetics understanding (Figure 6.7), evolution acceptance and evolution understanding (Figure 6.8) and evolution understanding and genetics understanding (Figure 6.9). All statistics are given beneath their corresponding figure. Similar weak to moderate relationships are seen before teaching, immediately after teaching, and three to six months after teaching. There is very little change between any of the correlations. Partial correlations have also been calculated and are found in Table 6.3. These reflect the stronger correlation between evolution acceptance and genetics knowledge than evolution acceptance and evolution knowledge.

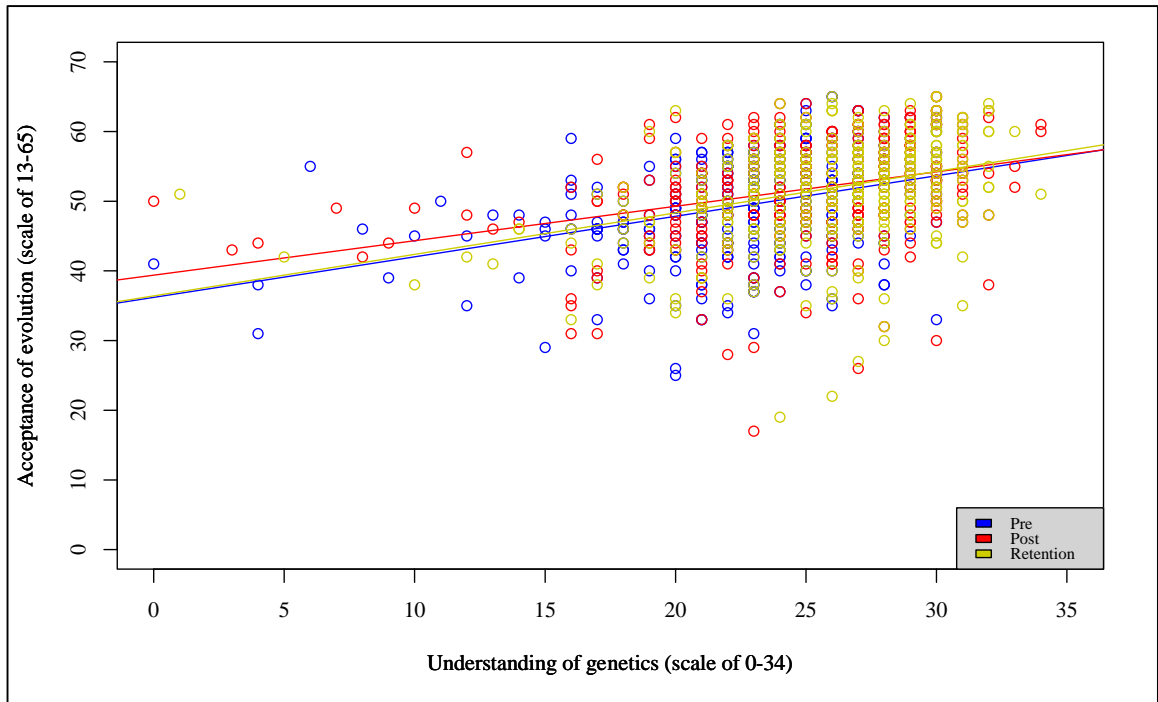


Figure 6.7 Acceptance of evolution and understanding of genetics before ($R_s = 0.36$, $p < .001$), immediately after ($R_s = 0.35$, $p < .001$), and three to six months after ($R_s = 0.35$, $p < .001$) teaching (pre N=388; post N=363; retention N=329).

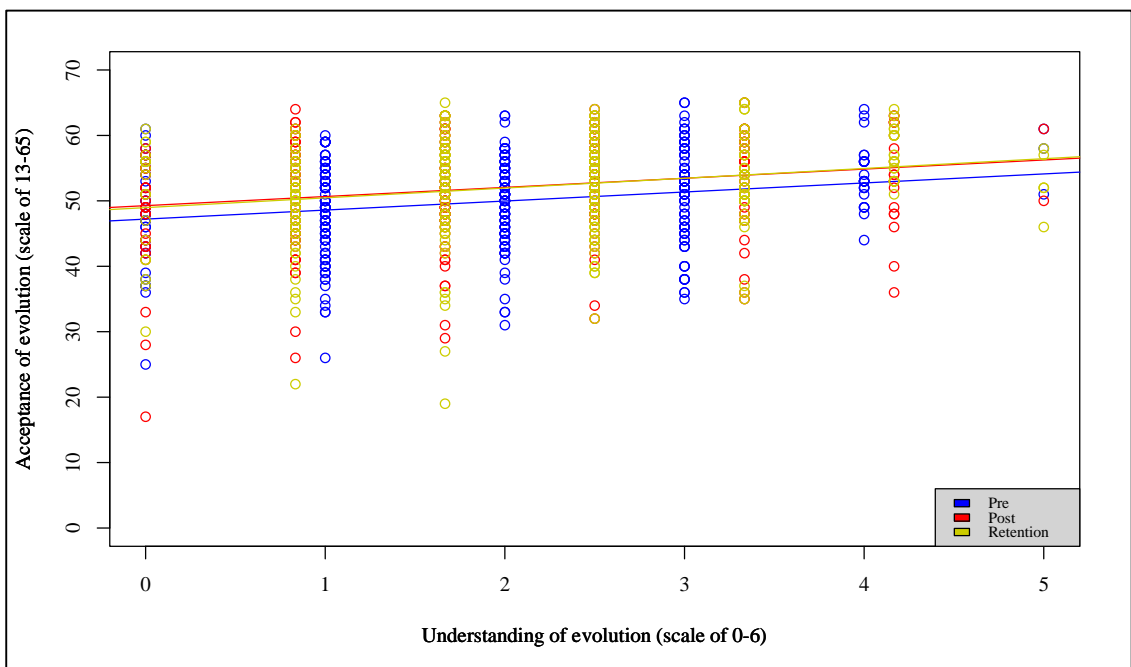


Figure 6.8 Acceptance of evolution and understanding of evolution before ($R_s = 0.21$, $p < .001$), immediately after ($R_s = 0.21$, $p < .001$), and three to six months after ($R_s = 0.22$, $p < .001$) teaching (pre N=379; post N=346; retention N=310).

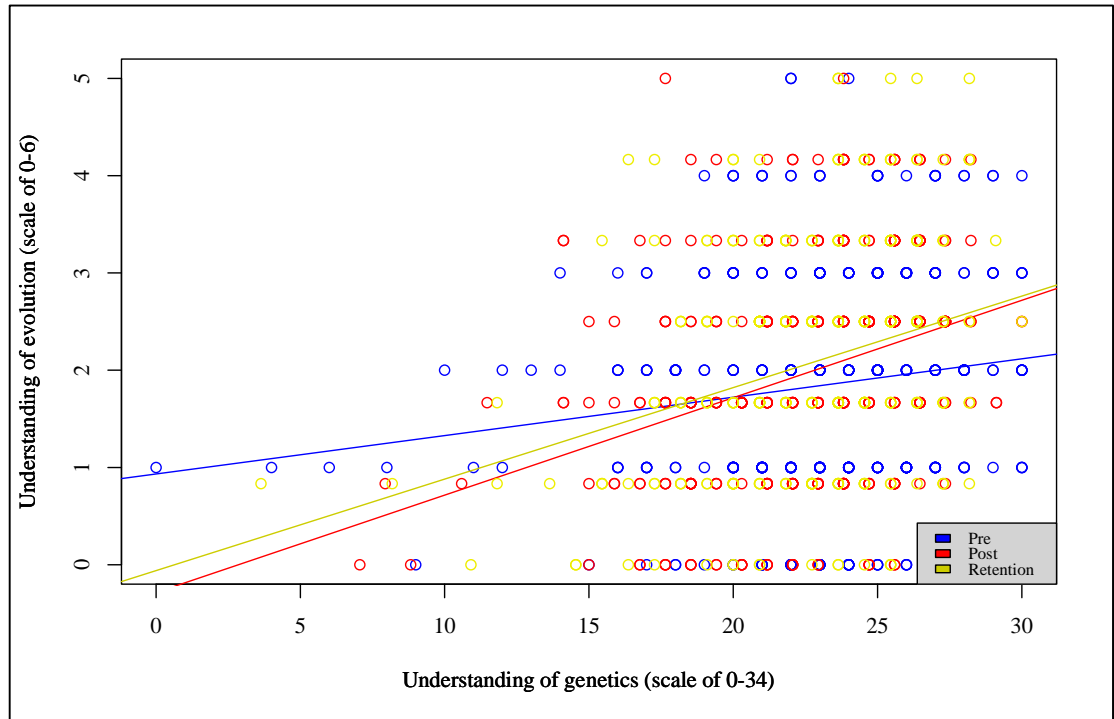


Figure 6.9 Understanding of evolution and understanding of genetics before ($R_s = 0.14$, $p = .008$), immediately after ($R_s = 0.35$, $p < .001$), and three to six months after ($R_s = 0.27$, $p < .001$) teaching (pre $N=379$; post $N=336$; retention $N=310$).

| R_s | Pre | Post | Retention |
|---|--------|--------|-----------|
| Evolution acceptance and genetics knowledge, given evolution knowledge | 0.339 | 0.287 | 0.28 |
| Evolution acceptance and evolution knowledge, given genetics knowledge | 0.2012 | 0.1591 | 0.1853 |

Table 6.3 Partial correlations between evolution acceptance and genetics knowledge, controlling for evolution knowledge and evolution and evolution knowledge, controlling for genetics knowledge. All correlations are highly significant ($p < .001$).

6.4 Summary and implications for teaching

In this chapter we have demonstrated the lasting impact that teaching has on evolution acceptance, genetics knowledge, and evolution knowledge. This appears to be true for different ability groups, although a small lower ability sample size has limited comparative results. Small sample sizes also mean it is difficult to tell whether topic order is important in long term acceptance of evolution and understanding of genetics and evolution. The relationships between acceptance and understanding remain moderately positive before and after teaching.

The majority of students accept evolution following their only compulsory education on the topic. This is encouraging. However, it appears to be those few students who rejected evolution prior to education that continue to show low acceptance after teaching. Education appears to impact those who were previously undecided. Despite the positive effects of teaching, there are still many misconceptions that students hold, particularly related to evolution and inheritance of acquired characteristics. These misconceptions should concern science educators. Ideas for teaching activities which could be used in an attempt to improve the situation are considered in Chapter 9.

Chapter 7. Focus groups

Informed by interpretations of data from the student questionnaires, we now concentrate on findings from the focus groups. We report that students generally enjoy learning about evolution and are interested in the topic, particularly human evolution and aspects that relate to us personally. Although mainly accepting of evolution, students struggle to speak accurately about evidence for evolution and their knowledge appears somewhat superficial. A number of students speak of evolution in terms of genes and alleles. Many common misconceptions exist relating to recent human evolution and ideas associated with Lamarckism persist. Religion is a contentious issue for numerous students, with some students envisaging conflict between the two, or having to choose one over the other. Those students who are religious find comfort in knowing that their faith has a positive stance on evolution. The importance of authority figures seems fundamental for many students.

The previous three chapters have all involved the analysis of quantitative data. In this chapter, qualitative data from the student focus groups shall be discussed. This was collected to help understand responses from the questionnaires and to gain further insight into students' views on evolution. During the focus groups, a number of interesting themes emerged. Some of these were asked specifically as questions during the focus groups, other important ideas became apparent during the discussions and on analysis. Many of these are clearly connected.

Aims of these focus groups, details of the design and methodology in developing the focus group, and an overview of the data, can all be found in Chapter 2. Here, responses to the key questions asked during the focus groups are examined. First, a descriptive discussion of student responses is given, followed by discussion of key themes that these discussion groups have revealed. Comparisons between schools and age groups, and also with responses to the student questionnaires, are contemplated. Finally, implications for teaching are discussed.

7.1 Key questions

These questions broadly formed the structure of the focus groups (see Appendix B). Not all questions were asked in all focus groups or to every student, and not all questions were asked in the same order. In analysing and presenting these findings, student responses are discussed under the question or theme which they are best suited to, rather than chronological ordering of the questions.

7.1.1 What does ‘evolution’ make students think of?

To introduce the topic, students were asked what the first thing they thought of when they heard the word ‘evolution’ was. These words are displayed as a word cloud below in Figure 7.1.



Figure 7.1 Word cloud showing what first comes to mind when students hear the word ‘evolution’ (word cloud generated at <http://www.wordle.net>).

‘Darwin’ was by far the most common answer, with numerous students mentioning his theory and natural selection too. The second most popular word was ‘monkeys’ with some students mentioning monkeys changing or developing into humans. ‘Apes’, ‘chimpanzees’ and ‘gorillas’ were also mentioned. A few students also described the picture showing gradual change from monkeys to humans. It is clear that many students think of links to humans (through monkeys and apes) even if they do not say this directly.

A number of students spoke of ‘change’ or ‘transition’ with some mention of ‘progress’ from simple to more complex beings or the idea of ‘growing’. Some students spoke of ‘time’ in reference to changes taking place over time and to evolution occurring over a long period of time. One student spoke about ‘genes’. The perceived ‘controversy’, ‘contradiction’ or ‘battle’ between science and religion was seen as important to a small number of students, and ‘god’ was also mentioned.

These initial thoughts are encouraging and suggest that students are aware of key terminology, concepts and theories in evolution; however misconceptions regarding progress from simple to complex organisms are already apparent. There is clearly much interest in human evolution, and also some in dinosaurs. It also appears that perceived conflict between science and religion are important to some students.

7.1.2 How do students know about evolution before secondary school?

Given that students clearly had opinions and some knowledge of evolution in the pre teaching questionnaires, prior to their compulsory school evolution education, questions pertaining to where these ideas had come from were asked in all focus groups. Most students could not remember when or where they first learnt about evolution. Many felt it was something they knew from quite a young age but didn’t necessarily understand or know much about, like student 3140104 who “kind of just knew” (314FG2, page 3):

3170219: “We never really talked about it but it was always there [...] we always knew about evolution.”

(317FG1, page 7)

3180102: “I can’t think of a set time where I first sort of heard of evolution or anything. It’s always sort of been there in the background”

(318FG2, page 6)

Some students had heard of evolution before but didn't know what it was until secondary school. However a small number of students were able to remember when they had first heard of evolution, such as student 3300123:

3300123: "It was when I was at the zoo one time when I was about seven or eight-ish and then my brother told me that we came from monkeys and I thought he was lying so I looked it up on the internet."

(330FG1, page 4)

This student was initially very surprised at this, much to the amusement of other members of the focus groups. This immediately highlights a common misunderstanding about human evolution, i.e. that humans have evolved from monkeys that still exist today.

Many students thought they had initially encountered evolution outside of school. Popular responses as to where they had heard about evolution from included parents and other family members such as grandparents and siblings. Television was a popular source of evolution information, particularly documentaries such as those presented by David Attenborough (who was mentioned frequently), but also through children's' programmes such as *Horrible Histories* (which included a Charles Darwin song that was mentioned on a few occasions). Fictional programmes such as *Planet of the Apes* and even *The Simpsons* were mentioned for their portrayals of evolution. The News was cited as being important in alerting students to up-to-date information, such as the discovery of a new species. Books and the internet were also common sources of information. Quite a few students mentioned the popular t-shirts which depict monkeys evolving into man (the potential misconceptions related to linear progression that such images promote should be noted). Some students remembered evolution exhibits at museums (sometimes part of a school trip) and visits to zoos.

For a number of students, their local area was very important due to ties with evolution. This was particularly apparent for students from school 329:

0290001: “We’re quite lucky here cos Darwin grew up in Shrewsbury.”
(329FG1, page 4)

Students from this school had visited Darwin’s house and monument, seen sculptures and paintings of Darwin, and had been to the Darwin Shopping Centre. These students felt they had been aware of Charles Darwin from a young age and that there was lots of information about Darwin and evolution in local museums. All students spoke positively about this.

Similarly, students from a school in Lyme Regis had visited some of the local museums; however, these students felt they were somewhat limited. Interestingly, no students from this school mentioned that Lyme Regis was important for fossil discoveries or seemed to know about Mary Anning. Perhaps schools such as this could make more of their local history and resources, where they are so applicable to evolution.

Local museums did appear to be important to some students. For example, students from a school in Gloucestershire spoke enthusiastically about visiting Bristol Museum and remembered learning about evolution there. A number of students spoke of visits to museums and zoos in London. These schools did not seem to be particularly restricted to any one region, and were mentioned by students from schools in the South East and the South West of England.

Nearly all students spoke of these sources of information in a positive manner, with many showing interest and enthusiasm towards the subject. Student 3180107 described how watching a TV programme about monkeys, apes and humans led them to feel “bonded with Tarzan” (318FG2, page 7).

Having heard of evolution, a small number of students had become very interested in it from a young age and had actively researched the topic independently, such as student 3180101:

3180101: “I must have been maybe five, six years old when I first heard about it. Erm, and it just intrigued me, so I went to find out more

about it [...] I've been picking up books from the libraries, buying books, erm, reading on the internet, all these different things just to try to find out [...] for myself."

(318FG2, pages 5-6)

Around a fifth of the students involved in the focus groups remembered learning about evolution in primary school; however those students felt they had only covered evolution in a very basic manner. Student 3180104 thought this was where their previous misconceptions had come from.

3180104: "We kind of watched er, a little cartoon thingy in either Year 3 or Year 4 but, yeah, it was just like the thing where the monkeys grow into the humans and, yeah, well that's kind of where my theory came from."

(318FG2, page 7)

The student then described how they discovered in secondary school that what they had learned in primary school was actually not correct. Other students alluded to not really understanding what was taught in primary school.

Only a small number of students thought they had learnt about evolution in secondary school science classes, prior to their recent biology lessons, and nearly all of these were from one school. A few students identified that they had learnt topics such as adaptations in science, earlier on in secondary school, and that this was linked to evolution, but that they did not specifically learn about evolution or genetic changes. A small number of students spoke about evolution being discussed in Religious Studies (RS) classes before learning about evolution in science classes. Student 3170206 described this as looking at "both sides" (317FG1, page 5). A few students had studied evolution in ethics classes, which student 0290001 described as "the contrast in theories" (329GF1, page 5). A couple of students thought they had learnt about Darwin and his voyage to the Galapagos in history classes. For most students, their recent science classes were the first time they had formally learnt about evolution.

7.1.3 What are students' views on learning about evolution?

Students were asked about their recent evolution lessons. This was to better understand the types of activities that had a positive impact on students with a view to evaluating resources used and incorporating ideas into the GEVOteach resources (this will be further discussed in Chapter 9). Questions varied depending on the responses of students but typically involved some discussion of whether students enjoyed learning about this topic and whether they thought it was important to learn about evolution.

7.1.3.1 Evolution lessons

Nearly all students remembered learning about evolution in school recently (most focus groups took place within a couple of months of students learning about evolution and genetics; however this did vary, particularly for sixth form students, some of whom hadn't studied evolution in over a year). A small number of students felt they hadn't learnt much about evolution specifically, but that they had covered topics such as selective breeding (for example, school 317). This is likely to have been a reflection of the exam boards these schools used. All students in these groups were still willing to discuss evolution, regardless of how little they felt they had learned about evolution.

Practical activities appeared to be particularly memorable for students. For example, variations on a 'bird beak' practical where students used different 'beaks' (implements such as tweezers) to try to pick up 'food' (different objects such as pasta), were mentioned a number of times. Other activities included using sweets to model DNA, a game where students picked characteristics to produce different pictures of dogs, and an activity where students moved across the classroom and attempted to copy other students (presumably to demonstrate that evolution is random).

Although practical activities proved popular and enjoyable for the majority of students, they did not always appear to help with understanding. For example, the copying activity mentioned above: although students were clearly excited to describe what they did, they struggled to explain how this related to evolution or the purpose of the activity. There were students who thought some of the

activities were very simplistic and it was easy to understand the theory behind them without repeating the exercise. For example, student 3300210 found the bird beak practical somewhat pointless:

3300210: “[I] Didn’t really find it that useful though. It’s like, you can kind of understand it without doing it.”

(330FG2, page 14)

Of the GEVOteach resources (which will be discussed in Chapter 9), the rock pocket mice lesson proved successful. Not only did students speak enthusiastically about related activities, but students appeared to have a good understanding of natural selection from this: students were able to speak about how being a particular colour would be an advantage in certain environments as mice were better camouflaged from predators. Some students were able to explain how DNA, mutations and alleles related to fur colour of the mice. This feedback suggested that these resources helped students to learn about natural selection effectively. The true or false misconceptions activity was also mentioned with some enthusiasm and students were able to discuss how they learnt that humans did not evolve directly from monkeys, but from a common ancestor.

Some students did not remember specific activities but lessons or ideas that seemed memorable included learning about Charles Darwin and the Galapagos. A number of students discussed how they found learning about different theories interesting, particularly Lamarck and giraffes:

3140202: “It’s a stupid thing, innit? Like their neck doesn’t actually get longer!”

(314FG1, page 3)

A number of students seemed particularly interested in Darwin and how the theory of evolution became popular. Some students, such as 3180102, were surprised that it was only relatively recently that we first became aware of evolution:

3180102: “I think of evolution as this sort of basic thing that sort of everyone knows about, and sort of talks about and sort of – they feel quite confident knowing that evolution is what it is. But then you think about it [Darwin’s theory of evolution by natural selection], it wasn’t really that long ago at all. It was literally – I’m not going to say how long it is because I don’t know but it was more recent than I would have thought it was [...] In terms of discovering actually discovering it with Darwin and knowing what it was about because it seems like it – considering how long humans have been around and evolving and everything, we’ve only just sort of recently discovered what it is and what it means.”

(318FG2, page 3)

Natural selection was also frequently mentioned with finches and giraffes being the most popular responses. Peppered moths were also described. Less common answers included foxes and camouflage toads. The similarities between related species were discussed and common ancestors were mentioned by a few students.

A small proportion of students immediately linked genetics with evolution and were able to describe how changes are caused by mutations:

3280303: “Genes, I enjoyed doing genes and stuff, I found that really interesting, how genes are passed on through natural selection.”

(328FG1, page 4)

3290107: “Um, a gene in the cell mutates [...] and it changes a characteristic and they might be better or worse suited to the environment.”

(32FG2, page 3)

7.1.3.2 Enjoyment and interest

There were a wide variety of opinions regarding how simple or how complicated students found evolution to learn about. Regardless of this, the majority of students enjoyed learning about evolution and found it an interesting topic. (Although this is perhaps unsurprising, given that participation in the focus groups was voluntary.) Most students involved in the focus groups stated that they did enjoy biology lessons in general, but many felt evolution was a particularly interesting topic. Not all students were able to give reasons as to why they enjoyed learning about evolution but for many the relevance to us and our place in the world appeared important:

3020121: “I just found out where we came from.”

(302FG1, page 5)

3120415: “I found it interesting because you can see like the similarities between how everyone has changed, like everything has changed, and you can go back and see how that happened.”

(312FG1, page 3)

3140203: “We always take a bit more interest in learning about subjects that we can relate to [...] so we care a little more about them.”

(314FG1, page 4)

3290115: “Something you can relate to and actually make sense of.”

(329FG3, page 4)

Other reasons for enjoying learning about evolution included that, for some students, it was quite a broad topic compared to other concepts in biology and included lots of different examples of animals and plants. A number of students simply said they enjoyed learning something new and that it wasn't repetitive in the ways that lessons on other topics, such as cells, could be.

7.1.3.3 The importance of learning about evolution

Many students felt it was important to learn about evolution. This was generally for similar reasons as to why they found evolution interesting and for some involved links to curiosity and important questions we have about ourselves:

3140104: “Just how can you not learn about how we were formed?”
(314FG2, page 5)

3180104: “I think it is because everyone’s got that question of like, ‘oh how did we come here or are we like aliens or something?’ I think from an early age you’re still kind of curious so I think learning it in school will finally answer that question otherwise you’re just going to go through life wondering.”
(318FG2, page 11)

3180101: “The fundamental questions at a young age: where did we come from? How did we get to where we are [...] You see pictures of dinosaurs as a kid and then you think, if that was then, this is now, where’s the change? What happened?”
(318FG2, page 12)

Some students, such as 1060104 thought of evolution as important in understanding life and philosophical questions:

1060104: “Its not just about science, its about whole life, why we are how we are, and how we could develop further.”
(306FG1, page 9)

Students such as 3280101 were keen about to talk about the importance of knowledge of evolution for understanding other aspects of biology and science:

3280101: “I think it’s really essential because it’s how you know, plants are, trees are, people are the way they are and you can’t have a decent

understanding of the natural world without understanding evolution really.”

(328FG1, page 15)

Similarly, a number of students were able to say that evolution was very important in many ways, but most struggled to give any examples:

3280203: “Yeah I think it’s important because it kind of links to loads of different things and kind of makes you appear to understand the world a little bit more.”

Facilitator: “Could you give us an example of the things it links to?”

3280203: “Well it links to loads of different subjects in school, and loads of different issues around the world and stuff. Nothing specific.”

(328FG1, page 15)

There were, however, a few students said that they did not enjoy learning about evolution. They found it quite boring and there were a too many worksheets and textbooks used in lessons. A small number of students didn’t feel it was important to learn about evolution. This tended to be as they felt it didn’t impact them in any way or was not important to their future:

3140216: “I don’t think it’s as important as like some other subjects because it’s not gonna affect you like if you’re gonna get a job or anything based on it.”

(314FG1, page 8)

3140202: “So, not like it’s a bad thing to learn but it doesn’t interest me.”

3140213: “Yeah, same sort of... It doesn’t really impact on my life.”

(314FG1, page 9)

7.1.3.4 Unanswered questions

Many students felt that they still had questions that they would like answered about evolution. A number of students suggested they would have liked to have learnt about how simple organisms evolved and, for student such as 3020105, “what started it” (302FG1, page 6). Student 3290124 felt they only started learning about evolution “in the middle” (329FG2, page 19) and wanted to know more about early evolution. Other students were more interested in disease and how mutations were involved in illnesses. A few students felt that they knew that mutations happened, but they didn’t understand the mechanisms behind how they worked and what actually happened inside genes. Another student felt that Wallace should be taught more in schools. Many students felt they would have liked to have learnt more about evolution in general and to have spent longer on the topic, especially students, such as those from school 329, who recognised how important evolution is within all biology:

0290002: “For some reason I think it could be made more of a thing. Because the way I remember it being taught was this is just another thing that we’re teaching on the curriculum. But it is actually something that is really essential.”

0290001: “Yeah.”

0290002: “Kind of science, it’s like...”

0290001: “It’s kind of the basics.”

0290002: “It’s really really important.”

0290001: “The basis of the whole thing [...] I think they’re a bit sort of ‘we can’t put too much emphasis on it because...’, cautious.”

0290002: “Yeah. Cautious [...] So I think they maybe could put a little bit more emphasis on it. Maybe a bit more on genetics, although that’s

a bit different because it's more complicated. [...] Because it [evolution] is important to know about.”

(329FG1, pages 14-15)

7.1.3.5 Evolution in primary schools

Although not directly related to this research study, the introduction of evolution to the primary curriculum is an important recent change within UK science education. This was discussed in a number of focus groups. Most students thought that evolution should be introduced in school at a younger age, with many thinking that evolution should be taught to primary school-aged children. This was for a number of reasons. Many thought that it would be useful to understand the basics of evolution from a younger age because the topic can be difficult to understand at secondary school, especially if they don't know much about it already. They felt that if students already had some knowledge of the basics, it should help them in secondary school:

3120415: “I think it is a good idea to be taught young so that you have, you know, a good understanding of it before, so if you get taught the basics in primary school, you can, then come secondary school you get taught like more difficult stuff.”

Facilitator: “Okay, so you've already got the basics?”

3120415: “Yeah, so you won't have to go over the basics in secondary.”
(312FG1, page 5)

3180102: “It means that it's a lot easier to teach it in secondary school because they already know about the fundamentals of it.”
(318FG2, page 9)

Some students thought it was important that students heard about different explanations to life other than religious ones. Students such as 3270120 described this as knowing about ‘both sides’ and mentioned the importance of allowing students to form their own opinions:

3020121: “So they don’t get other ideas [...] I’m not saying religion is wrong, but people could say it’s just like that, and then you could believe that when you’re older as well.”

(302FG1, page 7)

3140125: “I think they should be taught in primary school because then they can sort of form their own opinions on how we got here”

(314GF2, page 5)

3270120: “I think you should be presented with both sides of the argument from an early age so you can actually make your own decisions instead of indoctrinating you with one side.”

(327FG1, page 8)

A small number of students, typically those who had received a more religious upbringing or schooling themselves, felt that learning about evolution when they were younger was important. Students such as 0020001 felt that they had missed out on evolution education because they had not learnt about it in school:

0020001: “I think it’s a really good idea personally. I went to a Church of England primary school, and it was very, well, it was very Christian, obviously. Um, so I kind of, to say indoctrinated, it’s a bit too strong, but I got to like an age of 11 or something and I went into a bigger non-religious school and I sort of found myself looking back on Christianity, like biblical stories, thinking, ‘oh, did that not happen?’ Because it had been taught as if it were history, So I am thinking, yeah the introduction of sort of scientific, or just the idea of evolution can be really good.”

(302FG2, page 5)

Certain students recognised that evolution can be a very interesting topic for people of all ages. Student 1060104 appreciated that younger children could be enthralled by evolution. They described how their 10 year old brother was “absolutely fascinated by it” when evolution was taught in his primary school (106FG1, page 6).

However, a number of students recognised that evolution can be a complex topic. Sixth form students from 329FG1 thought that teaching evolution to primary school students was a good idea as long as it was just the basics and not too complicated. They suggested activities like taking fossils and bones into class or going fossil hunting. Other students felt that perhaps evolution was too complicated for very young children, with some suggesting it might be suitable for older primary school students, but not younger ones, who could get confused. Some students who had learnt about evolution in primary school had been very confused by it and felt it should have been taught in a better way. A number of students thought that evolution was too complicated for primary school and better left until secondary school:

3180107: “I personally thought it should have been for secondary school because with evolution it does go on like cells and genes and stuff which primary school students might not be as familiar with [...] I thought it kind of took some years to like kind of develop an understanding, like a clear understanding for them to learn about evolution.”

(318FG2, page 8)

However this student was perhaps thinking of evolution in too complex a way, although clearly linking genes to evolution at primary level is likely to be inappropriate. Student 3180213 was worried that introducing evolution at an earlier age could cause conflict if students came from a particularly religious background:

3180213: “If some people were religious they might not agree. They might have been brought up to... maybe their parents have told them that

‘please don’t talk about it or listen about it’ [...] when you’re older you kind of have a bigger understanding. You should learn about it when you’re older.”

(318FG1, page 10)

Arguably this student is right to consider alternative views, but whether opinions such as these should impact what is taught, is clearly a more contentious issue. This caused considerable discussion among other participants of the focus group and, on hearing other perspectives, this student did change their mind as to whether evolution should be introduced in primary schools.

Other students were concerned that at primary school age, students are not old enough to form their own opinions, and for that reason, neither evolution or religion should be taught in primary school:

3270131: “I think for me we shouldn’t learn any until an age like now. Because now we’re learning to get our own, our own opinions, whereas when I was like five years old, the first thing that I would believe would be the first thing that someone told me. So if you presented me with evolution first, then I would go to evolution, but if you presented me with God first, then I would go to God. So I think you can’t do them both at the same time, so I think it is fair to wait to a later age [...] to do both. So don’t teach anything until the child is old enough to form their own opinions.”

3270113: “When you’re younger [...] you can’t understand that what they’re telling you isn’t actually what the truth is.”

(327FG1, page 8)

7.1.3.6 Evolution appears different to other scientific theories

Within some focus groups, discussion considered the nature of scientific theories. Students were asked whether they thought evolution was different to any other scientific theory, such as gravity. They were asked to give reasons for their response. All students thought that evolution was different to other scientific

theories. Some students identified evolution as being an explanation for life. They recognised that it might challenge religious and traditional explanations which have been held by people for a long time, prior to knowledge of evolution:

1020104: “Religion focuses on god-made life and so having another idea of how life was made, I think that would cause issues with religious people, whereas you could almost argue that gravity doesn’t cause life, it simply maintains life, so that means we’re not floating around in space and all dying, so people would have less of an issue with theories which would directly contradict their own beliefs.”

(302FG2, page 11)

A very small number of students referred to evidence for evolution and the time needed for this to become accepted by the wider community, alongside religious ideas:

3270120: “I think because millions of people, I mean for a long time before anyone even started to think about evolution, we’ve had religion being the only way to explain how we came here, you know, you look back and people needed an explanation and so that’s where religion comes in as an explanation in simpler times before we had things like science, and then when we had our ideas on evolution, not saying it has to ... I mean you don’t have to ... need religion anymore, but I think that is where it’s always...you’re always going...I mean if you’ve been believing in something for millions of years and then you suddenly find out that actually there’s this bloke over here that thinks something differently, I mean Darwin tells us that we’re really conflicted by it because he was a really strong Catholic, but he couldn’t dispute his own evidence.”

3270113: “I think it’s quite similar to where people discovered the world was round and that the sun doesn’t go round the earth, the earth goes round the sun and for a long time there was a lot of religion against

science dispute, but in time I think people just see that's the evidence."

(327FG1, page 15)

A small proportion of students spoke of potential religious implications but also the idea that evolution is very personal to us:

0020001: "I think it's just because it's so personal, it's about us rather than about, well it is about all living things, but gravity sort of seems quite impersonal to a lot of people. And it [evolution] contradicts religion, sort of almost directly, I would say."

(302FG2, page 11)

Some students suggest evolution is different from scientific theories such as gravity, because we can experience gravity but that it is more difficult to experience evolution. Students such as 3180107 have a perceived lack of the testability of evolution and comment on how we are unable to observe evolution. Again, misconceptions related to human evolution are apparent:

3180107: "Like with gravity and stuff, we can kind of test it out and stuff but then however, evolution we probably won't live long enough to test out if apes and chimps and stuff do actually turn in, evolve into humans."

(318FG2, page 23)

Students such as 3270129 think that because evolution involves large time scales it is difficult to understand, especially given that, in their opinion, evolution can't be observed:

3270129: "It's too big for me [...] and we haven't seen it, all we know is that it has happened."

(327FG1, page 16)

Overall, there appears to be a lack of appreciation for the scientific understanding of ‘theory’. Evidence was rarely discussed and, although some students recognise that scientific theories should be testable, students did not appear to recognise that evolution can be observed. Evolution does not seem to be categorised as a scientific theory in the way that may be hoped, with many students displaying little understanding of the nature of science.

7.1.4 How do students define evolution?

Students were asked to describe, in their own words, what evolution is. Most students were able to give a basic definition that included words such as ‘adapt’, ‘change’ or ‘development’. ‘Characteristics’ or ‘traits’, ‘environment’, and ‘survive’ were commonly used. Many students spoke of the long time needed for evolution to occur. The word ‘species’ was commonly used. Only very rarely were ‘populations’ referred to (e.g. student 3300102, 330FG1, page 3). Typical answers included ideas about species changing or adapting to better suit their environment:

327013: “The way that species have adapted to survive in different surroundings and useful characteristics that have been passed on.”
(327FG1, page 6)

3180218: “The changes that have happened over a long time depending on the environment.”
(318FG1, page 9)

3170219: “The development of species over time to adapt to its specific environment.”
(317FG1, page 8)

3280101: “The change in species that occur over time so that they’re more suited to their environment.”
(328FG1, page 8)

Terms such as ‘natural selection’ and ‘survival of the fittest’ were sometimes used as a definition. Further probing of such responses tended to reveal naïve or simplistic understanding, as student 3290128 demonstrated:

3290128: “Survival of the fittest.”

Facilitator: “Could you explain what that means?”

3290128: “Um, er, if you’re not very good you’re gonna die.”

(329FG3, page 3)

Some students suggested evolution always led to improvement or more complexity. ‘Progression’ was used quite frequently:

3180216: “I think it’s like life developing over time from like simple forms to more complex forms.”

(318FG1, page 11)

3270113: “Progression from a less developed sort of species to a more developed that can handle its environment better.”

(327FG1, page 6)

However, there were a small number of students, such as 3180217, who specifically note that evolution is not always an improvement:

3180217: “How things changed over time but maybe some are for the better and some are for the worse.”

(318FG1, page 11)

Interestingly, some students considered genetics and included genes and mutations within their definitions of evolution. It is encouraging that these students have some understanding of the relationship between genes and evolution, and are able to associate natural selection with genetics:

3120606: “It’s where there’s random mutations that help the animal survive in an environment which happens over a long period of time which makes it a different animals.”

(312FG1, page 6)

3180102: “The idea that animals have sort of adapted over like years and years and years. Erm but not like all of those adaptations were good so the whole natural selection thing is that the mutations that didn’t work, they sort of died out and the mutations that did work, they made those animals better fitted to how they sort of can go about their things.”

(318FG2, page 13)

3290107: “How genes have altered characteristics to better suit the environment.”

(329FG2, page 8)

These responses suggest that most students have a basic understanding of evolution by natural selection, with some students automatically considering evolution in terms of genetic changes. However, a number of misconceptions, particularly related to evolution resulting in improvement, were common.

7.1.5 Are students accepting of evolution?

The vast majority of students involved in focus groups were very accepting of the theory of evolution: they accepted statements from the student questionnaire related to evolution as an explanation for modern life, and human evolution. A key purpose of these discussion groups is to ascertain the reasons behind this acceptance, or, for those students who are less convinced, to explore factors that may cause students to reject evolution.

The reasons for accepting were perhaps surprising, with many students suggesting they accept evolution purely because it is intuitive and “it makes sense” (0290003, 329FG1, page 7). However, when probed further, most of these students

commented on evidence for evolution. As previously identified, particular interest was held in evolution that was relevant to humans:

3270113: “It just seems like it makes sense.”

Facilitator: “Why do you think it makes sense?”

3270113: “Because we have evidence to suggest that we weren’t always this way.”

(317FG1, Page 7)

Some students acknowledged that evolution could be a complicated idea to understand and accept, but that the amount of evidence facilitated acceptance. Although, as shall discussed in the next section, exactly what evidence students are referring to is not clear, even to the students themselves:

0290001: “It is quite a difficult theory I suppose, how things can change over so long from such a different... you know from a little microbe to a giraffe or whatever, but I think it’s acceptable because there’s so much evidence.”

(329FG1, page 7)

Some students, such as 3180104, struggle with aspects of evolution because they have not seen it for themselves, even though they know something about relevant evidence:

3180104: “I agree with it because there’s some evidence for it but I – for some parts of it I just don’t – I can’t kind of get my head around. Like horses with feet [...] Because I haven’t witnessed it myself... I kind of can’t know it happened. It’s like dinosaurs, sometimes I just don’t think they were really there.”

(318FG2, page15)

A number of students mentioned selective breeding as a means of seeing artificial selection and felt this had helped them as they could see obvious differences between different animals on farms. They thought that examples such as these could be useful in helping students to understand how evolution could operate on longer time scales through natural selection.

A substantial proportion of students thought evolution was more likely than other explanations, particularly religious ones. Some students, such as 3270131, spoke of ‘believing’ in evolution, regardless of evidence:

3020105: “I think it’s more realistic that religion.”

(302GF1, page 11)

3270131: “Well I believe in evolution because not everyone needs evidence, it’s just far more feasible rather than God made Adam and Eve.”

(317FG1, Page 7)

3290111: “It’s more realistic that the creation story. It seems like it could have actually happened, but the creation story doesn’t really have any evidence.”

(329FG2, page 14)

A small number of students rejected evolution. Those who struggled to accept evolution or showed preference towards alternative views tended to have strong religious beliefs:

3270122: “I disagree [...] I think that yeah maybe we could have evolved, I believe that we did evolve, but not so much of a big scale, because I don’t know, there’s just evidence for the Bible and for evolution; there’s evidence against evolution as well [...] I’m not saying we didn’t change and that everything was like this from the start, I just think we are taking it a little too far.”

(327FG1, page 9)

3290130: “Er, well, I don’t really believe in evolution. I do find it very interesting but because I’m a Christian, I just, I just don’t believe in evolution.”

(329FG2, page 9)

However, having a religious background did not appear to play such an important part for all students. 0290002 described how evidence for evolution is irrefutable and, for them, that meant they had to accept evolution, regardless of a religious upbringing:

0290002: “I’ve grown up in a Christian house. And I’ve always been at church my whole life and you have kind of the older generation who are a little bit iffy on it but then actually when you’ve learnt so much and you’ve seen the evidence and everything, it’s really hard not to. To kind of dispute it in any way.”

(329FG1, page 6)

7.1.6 What evidence for evolution do students know about?

As is clear from the previous section on evolution acceptance, the term ‘evidence’ is commonly given as an explanation for evolution acceptance. In order to better qualify this, students participating in the focus groups were asked what evidence for evolution they knew of, and if there was any piece of evidence they found particularly convincing or had lead to them accepting evolution. A variety of evidence was discussed.

One of the most popular examples of evidence for evolution was Darwin’s finches. Students were able to discuss basic ideas around finches and how their beaks were adapted to eat different foods on different islands. Some students discussed Darwin’s theory in more detail and spoke about his journey on the Beagle to the Galapagos. Often this gave a more historical perspective, with little mention of any of the other species Darwin studied or evidence he reported.

Many students gave fossils as the main evidence for evolution. However, not many students were able to describe these in any detail or give many examples.

One student knew that different fossils could be found in different rock layers. A few students were able to describe transitional fossils, such as student 0290002:

0290002: “The fossil record.”

Facilitator: “Could you tell me a bit more about that?”

0290002: “There’s the remains of very early life forms but also you can see how they have changed to more modern day forms, and is it archaeopteryx or something... shows the transformation from dinosaurs to birds I think it is, yeah.”

(329FG1, page 7)

Students clearly appreciated examples that they could easily observe for themselves and found this the most convincing evidence:

0290002: “I think the fossils and the homologous structures... it’s kind of, it’s something you can look at and you can see it, you know I can see it with my own eyes sort of thing. So it’s something that’s there, because you can actually see it yourself.”

(329FG1, page 8)

A number of students described how species that are well adapted to their environments are evidence for evolution. A few students spoke of extinction, due to species not suiting their environment or because an environment had changed rapidly, as convincing evidence. These students did not give named examples but suggested there were examples that had happened in their lifetime. Quite a lot of students spoke about the similarities between species, with those more closely related being the most similar. Some of these students spoke about noticing this whilst visiting zoos. Many students linked this to humans and apes and spoke not just about physical characteristics, but also about mental ability and emotion:

3170219: “You just see it with humans, I don’t know, like we’ve just adapted from monkeys. If you see apes and stuff we are kind of similar and it just proves that evolution... how it does work.”

Facilitator: “Okay. What ways are we similar to apes or monkeys?”

3170219: “Just like the way like... the way we move and like use our hands into like ...Erm, just like the way like we move and sometimes you can see like with monkeys like the way they show affection to their children, stuff like that. It’s kind of the same as humans.”

(317FG1, page 9)

A couple of students described antibiotic resistant bacteria as an example of evolution. This topic is included in most GCSE syllabi, but is rarely included within genetics or evolution modules. Students from school 328 appeared to have learnt about antibiotic resistance within the context of evolution and these particular students felt examples such as this were best as they could be easily seen in a human lifetime:

3280302: “The best evidence is that you can see [evolution] happen in bacteria, you can see it happening in real time almost.”

(328FG1, pages11)

Students’ perceive of these examples are all very interesting, particularly given that some students suggested they did not accept evolution when they were younger, as they did not have any evidence for it.

3290107: “I couldn’t see it happening so I thought it wasn’t true for a while.”

(329FG2, page 7)

Other examples given as evidence for evolution include common ancestors, and natural selection examples such as peppered moths, rock pocket mice and fruit flies. A few students, particularly those studying biology at AS or A Level

Biology were able to talk about evidence such as comparative DNA or genetic profiling, embryology and homologous structures, but these were not discussed in many focus groups.

Human evolution was a popular theme. Some students mentioned Neanderthals, but most simply spoke of early humans or cavemen. Examples of changes included skull shapes (some compared these to Neanderthals), teeth, feet and skeletons. Recent changes in human height was another common example of evolution. Students spoke of being able to see lower doors in older houses as evidence that humans were shorter in the past, and concluded that this was evolution. Students found it difficult to distinguish between reasons for changes, and to acknowledge that not all changes were due to evolution. When these ideas were challenged, students were sometimes able to rethink their ideas:

3270120: “You can see it in humans as well; humans are getting taller, if you look in the 1500s we were actually, you know, the average height would probably have been around 5’5”, now it’s... for a man it’s 6ft probably?”

Facilitator: “Is that purely because of evolution?”

3270120: “I think that would... that one... that example would probably [be] a little bit to do with evolution, mainly to do with environmental changes and just you know characteristic things can’t stop.”

Facilitator: “What sort of environmental changes?”

3270120: “I don’t know like... things like you know society changing, things like that, and also maybe taller people would have been more attractive and that characteristic gets passed along.”

(327FG1, page 7)

Students within focus groups were usually able to assist with such misconceptions, but in some discussion groups, other students either didn’t

recognise these misconceptions or were unwilling to challenge them. Some students seemed very confident in their knowledge of evolution, but they clearly had underlying misunderstandings about whether behaviours are learned or acquired:

3270120: “In my opinion I think that there’s undisputable evidence for it [evolution] and we’ve got things like fishes and seals who follow boats because they know they will chuck out fish they don’t want – that’s a perfect example of it in our modern day.”

(327FG1, page 7)

Although students such as 3270120 in the above example could sometimes appreciate there was confusion surrounding ‘nature and nurture’ when they were challenged, they repeatedly showed the same misconceptions throughout their focus group:

3270120: “I think there is undisputable evidence of evolution and you’ve got countless examples. You’ve got the finches that Darwin observed, you’ve got things like in the Galapagos there’s sea lions and they come onto the beaches and they go through the markets and they go and pick up the fish that they eyed and because they do this, people feed them and then more come and you even see it with what is it...seagulls and things, if you continue to feed a seagull in one place he’s always going to come there isn’t it, and come back and more are going to come and the seagulls will probably breed and that will pass down that inherent thing to go there.”

(327FG1, page 12)

These confusions over the heritability of acquired characteristics are clearly deep rooted among some students and teaching does not appear to have ignited the conceptual change needed to overcome such perceptions. However, this lack of understanding clearly has not affected this students’ acceptance of evolution. Intriguingly, it appears to have enhanced it.

Overall, students seemed to think that there is a lot of evidence for evolution and that this evidence was incredibly important. Some students alluded to the fact that evolution would not be taught in schools unless such evidence existed:

3300222: “Yeah I think there is sufficient evidence [...] there wouldn’t be loads of point teaching something in schools that you didn’t know definitely existed. It would be a bit like teaching Romeo and Juliet’s play or something in an English class but there isn’t a play to teach about.”

(330FG2, page 10)

However, many students struggled to describe much evidence for evolution, even when they had previously said that there was a lot. Some students stated that they were surprised at how little evidence there is and that they were expecting better or more obvious evidence:

3180104: “There’s not as much evidence as I thought there would be with like the amount of people believing this theory.”

3180101: “I do believe there’s enough evidence to support it. Maybe not as much as I’d hoped. There is a lot of evidence but not as much as there should be I think.”

3180104: “I suppose I was kind of expecting like a movie kind of, kind of piece of evidence. Like you know how they find like the cavemen like frozen in, in ice or something. So I was expecting like a full body, early human. But instead we’ve just got bones but then – and fossils could be like from anything so it kind of feels like people are just speculating like what it could have been.”

(318FG2, pages 18 - 19)

It is somewhat concerning that students feel this way regarding the evidence for evolution, especially given these are students who are interested in evolution and keen to learn about it. However, this is likely to reflect exam specifications which stipulate little evidence for studying, namely fossils and finches.

7.1.7 Do students make links between evolution and genetics?

There were quite a few students who immediately started talking about evolution in terms of genetics. For example, the first word that student 3180107 gave when asked what they first associate with evolution, is “genes” (318FG2 page 2). Students from school 317 start talking about genetics and mutation when asked what they remember learning about during their evolution lessons, as do students from schools 328 and 330:

3170219: “Erm, well, like if something is like born with a mutation that can aid, like help, in any way, it then passes it on to the next generation which is like evolution, it starts off with a mutation that helps another animal have an advantage.”

(317FG1, page 4)

When asked about whether there are any links between evolution and genetics, a small number of students did not think the two were particularly linked. Some students acknowledged that evolution was linked to genetics, but were not able to give much information or any examples. Other students were more comfortable speaking about the two topics in a combined manner and described comparative DNA or genetic profiling, and were able to give an indication as to how genetically similar humans are to other organisms, such as bananas, but more closely related to apes. Some students linked this to classification and common and recent ancestors. Other students spoke about mutations and their importance in evolution. Some students were able to give examples, such as warfarin resistance in rats. Some spoke about similar adaptations in particular environments, and how it is genes that control for these features.

Certain students, such as 3270122, were clearly enthusiastic about links between genetics and evolution, and acknowledge the importance of genetics in providing further evidence for evolution:

3270122: “I think it’s amazing that we have linked our change in genetics to how we came to be. I think it’s really hard evidence for evolution.”
(327FG1, page 17)

Other students appreciated that without genetics, evolution could not happen:

3140104: “DNA kind of controls evolution. Like, if that doesn’t change nothing is going to change.”
(314FG2, page 13)

0290002: “The whole point of evolution is the mutation in the genetics and it’s whether that mutation is suitable for the environment and it’s whether that one carries on [...] you can’t have evolution without genetics [...] the two go hand in hand really, you can’t have one without the other.”
(329FG1, page 9)

Nearly exactly the same wording as was used by student 029002 was used by students from school 330:

3300114: “They go hand in hand, don’t they.”

3300113: “Without one you can’t have the other, really.”

3300103: “It’s sort of like genes are the more complex sort of explanation of the changes.”

3300113: “Yeah it’s just the same thing.”
(330FG1, page 16)

Some students were keen to discuss Darwin and his lack of knowledge of genetics. They were unable to comprehend that Darwin was able to develop his theory without knowledge of genetics, given how intertwined the two are:

3180102: “We talked about how Charles Darwin made his theory before he knew pretty much anything about genetics [...] but I feel like the theory does sort of depend on genetics but I don’t really know how he made it without genetics... I don’t know that. Because I feel like it depends on it so much. I feel like he should have known about genetics.”

3180101: “I’d go on from [3180102] in saying that it was almost as though I don’t think he would have been able to make it without genetics, because there was always the thing of when you’re talking about evolution you’ve got to mention genes. Mutations, how things change and it’s – it’s almost – it’s another question of how, how he made those links.”

(318FG2, pages 26-27)

Some students felt that evolution and genetics topics had been taught together or that lots of links had been made between the two. Many of these students thought that learning about genetics first had helped them to understand evolution. Other students did not think any links had been made at all. There were mixed opinions as to whether learning about evolution and genetics would make any difference to students’ learning these topics:

3290126: “I think it makes sense to have them together because they’re so... you have to have genes to have mutation to have change.”

(329FG2, page 16)

1020104: “I think it’s an improvement because it deepens understanding [...] so I think it would definitely be beneficial to teach them alongside each other, because there are lots of links and it would just help

[...] I think it's overlooked because the syllabus, at the moment, doesn't recognise it."

0020001: "I think the link is really important because it makes it more of a, a theory than just an idea."

(302FG2, pages 11-12)

Links between evolution and genetics were mentioned throughout many focus groups, often without any prompts, and sometimes links were made unexpectedly. During one discussion group, students spoke about MRSA and antibiotics. They were able to describe basic ideas yet were confused about detail. They were surprised to realise that this was evolution and that the bacteria were evolving. As previously noted, antibiotic resistance does not usually sit within genetics or evolution modules, but given its importance and potential accessibility for many students as evidence for evolution, it seems a pity that links are not being made between these topics.

A small number of students were able to speak maturely about where boundaries are made in scientific topics and realised that different aspects of science do overlap and compliment each other:

3280302: "Even the division of science is arbitrary and it's all just one giant knowledge, but just practically we have to split it up somewhere [...] you can't teach it all in one go, you've got to start somewhere."

(328FG1, page 13)

This seems an appropriate appraisal of the sometimes haphazard nature with which topics are introduced in schools. Although it is difficult to generalise findings from these focus groups, as they are very self selecting in terms of participants and likely to be highly impacted by teacher and class effects, it would appear that students see a logic in learning about genetics and evolution in a combined approach. It is encouraging to hear many students describe evolution in terms of genetics, although overall, knowledge of evolution appears quite

superficial with frequent examples of misconceptions. Perhaps this is to be expected, given the little coverage evolution receives within the national curriculum.

To conclude these descriptive findings from the focus groups, Figure 7.2 contains a word cloud of the most frequently used words throughout all the focus groups. Although this of course reflects the questions asked, it does provide a useful overview to commonly used words and hence implies some popular ideas and discussions. ‘Genetics’ is frequently mentioned, as are ‘evidence’, ‘humans’ ‘Darwin’, ‘DNA’, ‘mutations’ and ‘species’. ‘Interesting’ is one of the most frequently used words, perhaps representing the sentiment of many of the students regarding evolution.

To summarise, the focus groups have provided answers to numerous questions regarding evolution education: we have better understanding of how students are aware of evolution, prior to learning about it in secondary schools; we have gleaned information regarding teaching activities which may be useful in developing teaching resources; and we better understand reasons behind students’ views of evolution. We also have some idea of the types of links between evolution and genetics that students are aware of. Discussion groups have also highlighted a number of key themes, which shall now be discussed.

7.2 Key themes

Throughout the focus group process, key themes emerged. These were not asked about specifically through questions, but were mentioned in the vast majority of the focus groups in some way.

7.1.1 Science and religion

Science and religion was a central theme for a number of focus groups and an underlying idea in others. There were very mixed views about the compatibility of science and religion with some students thinking it reasonable to hold religious beliefs and accept evolution, but other students viewed science and religion as ‘opposite sides’. For some students, it seemed as though they had to pick between the two. Student 3020116 described it as “either one or the other” (302FG1, page 12). This seemed particularly true for a number of students who were not particularly religious themselves. When asked what came to mind on hearing the word ‘evolution’, responses from school 302 were focused on this perceived controversy between science and religion:

1020104: “The battle between religious folk and the scientific folk [...] As I’m not religious, I kind of pick the science side.”

Facilitator: “Do you think you’ve got to pick one or the other then?”

1020104: “I went to a Catholic primary school. And for the record, I didn’t enjoy it, but um, from what I recall about like the bible, and I didn’t read into it too much, it was like pick one. So, and I’ve always picked science. [...] I think, for me, the way I view it, it’s more kind of one or the other.”

0020001: “Um, interestingly enough, I also thought of the sort of the, controversy between creationism and evolutionism.”

(302FG2, pages 1-2)

The only other school where this rift between science and religion was quite so apparent was within the only faith school involved in focus groups. Here, there was much heated discussion between students. A number of the students were religious and very open to speaking about their beliefs and interactions with science:

3270123: “Because I’m a Christian and I believe in God and I believe that He created us and I believe that as we evolved God made us evolve and that’s how we are here today [...] Because I think like science is not meant to contradict God and God is not meant to contradict science, they’re meant to like go together, I think that’s what people mostly get wrong these days. Because I think as soon as someone mentions God it’s like, ‘Oh you’re against science and all the research that they’ve done’ but really we should be using science to help us to get further rather than to work out what happened before.”

(327FG1, page 5)

Although a number of these students, such as 3270123, had very strong religious beliefs, they generally thought that there did not have to be conflict between science and religion, and that they were open to other people’s viewpoints and trying to understand them. Most students did not take the bible in a very literal sense:

3270129: “The world wasn’t made in seven days, so I think if you take a really metaphorical sense and that isn’t actually what the Bible was saying [...] then science and religion can go together quite nicely actually.”

(327FG1, page 7)

3270123: “The science point of view is that the earth was created and it took a long time for the earth to be created and the religious point of view was that the world was created in seven days by God. You

could actually mix the two and think that one day for God on earth is actually thousands of years in real time.”

(327FG1, page 10)

Some students appreciated key differences between science and religion, however it was clear that students with very strong faith were not necessarily able to separate the differences between science and religion:

3270113: “If you have evidence it’s not faith anymore.”

3270122: “I think Christianity is something based on history and fact.”

3270129: “I would like to disagree. Because Christianity is based widely on faith, the definition of faith is strong beliefs without logical proof.”

3270122: “Obviously you can’t know everything, evolution itself you could class as a faith because you don’t know exactly what happened, but I... if you search well enough, I think you can find evidence for everything that happened in the Bible. I have seen evidence that has happened in the Bible and not because I was like brought up in a Christian family, but because I made sure that I’m not closed minded. So that I know what I believe and I know what you believe, so that I can be firm in my belief.”

3270120: “The idea of evolution being a faith is, um, quite strongly I disagree with. As [3270129] said a faith is something you have belief in with no logical reason for, right? There is countless amounts of evidence for evolution – that’s logical reasoning for believing in something, therefore it can’t be a faith. [...] there are holes, but there are considerable amounts of evidence for it and in my opinion you’ve got good evidence, you know, I think they pretty much proved that evolution is not theory, it’s fact.”

(327FG1, pages 10-12)

There is clearly confusion about definitions of science and religion among certain students involved in this focus group. It is concerning that student 3270122 considers classifying evolution as a faith but reassuring that other students do not follow this judgment. Students were very outspoken in their arguments. Should such opinions be vocalised during evolution classes, these may impact other students' learning and could lead to confusion and even dispute over the status of evolution and science, unless handled carefully. Interestingly, however, students such as 3270122 were keen to learn about evolution and were accepting of certain aspects of evolution.

Although no focus groups in other schools contained such passionate debate, evolution and religion were nonetheless topics many students were keen to discuss. A number of students held strong views on what should be taught in school and when. Some religious students felt that not just evolution should be taught in school, and that other explanations should be included too:

3290130: "I think it would be fair to balance it out."

Facilitator: "Okay. And do you think that would be right to do in a science class or do you think that's maybe something for an ethics-type class?"

3290110: "It's to do with science."

3290130: "[...] Well, it doesn't have to be during science because I know science is very 'evolution', very 'God doesn't exist' based, so I can accept that, but maybe during a different lesson, you know, just to balance it out a bit."

(329FG2, page 13)

Student 3290130 clearly felt that it was unfair that some sort of religious explanation was not given as well as evolution and seemed slightly uncomfortable discussing the subject. Conversely, some students felt that evolution wasn't taught enough in some schools, especially within some religious schools:

3270131: “Because I went to a Catholic school we didn’t talk about evolution, they only talked about God.”

(327FG1, page 8)

For some students, including those who were religious, there did not appear to be any conflict between science and religion where schools treated the two as separate entities. This approach seemed to make students feel comfortable:

0290002: “In school they’ve treated it as very different things [...] I remember being told actually when we did it at GCSE, you know this is a theory, you know you’re allowed your own views... I think it was really important [...] Yeah, ‘remember this is what we are teaching you but you can believe what you want’ kind of thing. Because I think that’s quite important.”

(329FG1, page 13)

Although ensuring that students are comfortable with subject matter, and that they do not feel that their personal beliefs are conflicted, may be considered important by teachers, this teaching approach could undermine the scientific importance of evolution. It is understandable that learning about evolution can be a worrying time for some students who are religious and who do not realise that they do not have to ‘pick one or the other’. One student in particular stood out for their openness in discussing this:

3180104: “I kind of remember evolution more than any other topic because it kind of changed my view on it in a way.”

(318FG2, page 5)

This student had initially felt uncomfortable about learning evolution due to their religious beliefs:

3180104: “I’m religious so that’s why I kind of find it difficult.”

Facilitator: “Thank you for sharing that. Did you find it quite difficult to learn about evolution then because of that or were you happy to learn?”

3180104: “Yeah, the first lesson I kind of – I kind of wanted to argue that actually God put everyone there but then I kind of also believe in science a lot so I was really confused the first lesson but – but then Miss was like ‘Oh yeah, the Pope actually agrees with some of the theories behind it’ so I kind of accepted it but don’t strongly believe in it.”

(318FG2, page 22)

For this student, having the knowledge that their religion accepted evolution was of vital importance. It ensured that they were able to learn about evolution and not cause any disruption to the class. It could be argued that there are underlying issues here and that ideally students should have better understanding of the nature of science and differences to religion. However, if this simple teacher intervention can ensure religious students are more comfortable and open to learning about evolution, this may appear a sensible approach to take.

Although this section raises concerns about students’ lack of understanding about differences between science and religion, it should be emphasised that nearly all students involved in the focus groups were interested and quite open to learning about evolution. The perceived conflict and opinion that students must ‘choose between the two’ appears more common among non-religious students. Poor appreciation of the nature of science, little understanding of what constitutes a scientific ‘theory’, and teaching approaches which suggest evolution and religious explanations are of equal standing in regards to student ‘belief’, may have a detrimental effect on the importance and perceived validity of evolution within classrooms.

7.2.2 Human evolution

It is obvious that students often think primarily in terms of humans. This is a particularly relevant aspect of evolution for many students, and clearly what interests them the most. The notion that humans evolved from monkeys or apes was the first thought for many students when speaking about evolution, and examples of evolution often involve humans (regardless of whether they are correct or not).

A number of students defined evolution purely in terms of humans, and when asked to talk about evidence for evolution, many students spoke about human fossils or skeletons and about similarities between humans and other animals, in terms of DNA and physical characteristics including skulls. Students often talk of ‘early humans’. Some students are able to qualify this and refer to other human species such as Neanderthals or specific fossils such as Lucy, but most students are more vague about what constitutes ‘early humans’ but are able to comment on differences:

3170219: “Early humans [...] They have much more muscle mass and their arms, like they’re much shorter and arms are much longer. It shows how we’ve changed like for the adaptation of our environment. So now we don’t really need to fight anything or like so we’ve got much like weaker arms and just the way [...] our heads are big.”

(317FG1, pages 11-12)

There was often confusion over reasons for changes in humans, as highlighted in the door height example earlier. Many students appeared to be describing a shorter time scale than need be considered for human evolution. For example, student 0060003 mentions changes in humans since “the olden days”. Some students thought of any changes as being evolution, whereas other students recognised that some changes in modern humans are due to nutrition and medical advancement:

3170219: “If you see like in the Medieval period people were a lot shorter than we are now and I think it was something to do...”

3170118: "...Er, can I? It's actually due to nutrition. So in recent history, say Middle Ages to now, it's not evolution [...] so we can actually, erm, fulfil our growth to our potential and we couldn't before."

(317FG1, page 12)

Some students were comfortable in accepting evolution in all organisms, but were particularly interested in the extent to which humans have evolved:

3290107: "I think we have evolved but like not as much as other animals have."

Facilitator: "Okay, that's interesting, why do you think that?"

3290107: "Because like other animals suit the environment but we haven't really suited an environment, we've changed the environment around us instead."

(329FG2, page 10)

Statements such as this lead to interesting discussions about modern medicine and intelligence. Many students were keen to discuss aspects of human evolution and enthusiastically debated whether humans were still evolving or how humans might evolve in the future.

Despite interest in human evolution, students hold many misconceptions. Many of these would appear easily identifiable but may be hard to correct. Interestingly, human evolution is not a specific part of all exam board specifications, and therefore it is possible that students have not actually learnt information about human evolution during school. If students are so interested in human evolution, this would seem an obvious aspect to include in evolution lessons.

7.2.3 The impact of authority figures

Throughout the focus groups, various important people were mentioned by students. Often these were influential in students' attitudes towards evolution, and many students were aware of this.

Family, such as parents, were often mentioned when students discussed where they had first heard of evolution from. Some students even alluded to the fact that people (especially younger children) tend to follow what their parents do:

3270129: “Even though it isn’t logical [...] children do it to mimic their parents – so they will forget logic to follow what their parents are doing because they look up to them.”

(327FG1, page 9)

A number of students stated that they accepted evolution as its what they had been taught. Some also complemented their teachers, such as student 1020104 who thought that their teacher “handled it brilliantly” (302FG2, page 8). Many students trust that what they are taught in school “is true” (3290110, 329FG2, page 13) and do not think they would be taught it otherwise:

3300220: “I don’t think that we’re being lied to at all because [...] I just don’t think it’s like a conspiracy theory.”

(330FG2, page 12)

Teachers who had particular interest or experience of working within evolutionary biology clearly impressed students and their enthusiasm was obvious:

3120606: “One of my teachers has actually seen evolution [...] He was talking about how he did evolution in fruit flies. Like over many generations, he changed them.”

(312GF1, page 8)

Some students were happy to admit that they accept evolution because its what they have been told or taught:

3020106: “Because that’s what we’ve been told and like, we’ve been told like basically...”

Facilitator: “Okay, so is that what you’ve been told through your parents? Through school?”

30120106: “Through a bit of both like, that’s what I believe.”

Facilitator: “Yeah, okay [...] and you’re agreeing there [3020116]?”

302116: “And I was told by my parents when I was younger because you believe, you believe what your parents say when you’re young. You still like a bit of evidence.”

(302FG1, page 11)

Interestingly, student 302116 does mention evidence here, in addition to believing what your parents say when you are young.

Important figures were not just people that the students knew. TV documentaries were commonly given as a source of information about evolution, and some students felt these, and their presenters were important in helping them accept evolution:

3170206: “Even in like TV programmes they make it really convincing as well.”

(317FG1, page 10)

3290128: “Well, if David Attenborough believes in it then why shouldn’t everyone else?”

(329FG3, page 14)

As already mentioned, these figures of authority may be religious, if this is important to individual students:

3180104: “I kind of just accepted because the Pope kind of believed in some of the theories that I could as well.”

(318FG2, page 24)

The importance of authority figures should not be undermined. Although students typically trust their parents when they are younger, they remain trusting of teachers, religious leaders, and even television presenters, as they grow older. Perhaps for this reason, it is vitally important that teachers understand the influence they can have on their students.

7.2.4 Misconceptions

A number of important misconceptions have been stressed throughout discussion of the focus groups. Misconceptions such as these are frequently documented but difficult to change. One commonly held misconception was that evolution is about improving or for simple organisms to become more complex:

3170206: “Trying to reach like the best level of standard, like achieve like perfectness.”

(317FG1, page 3)

3300117: “Starting off as a simple thing to becoming slightly more complicated, and eventually we may become slightly more complicated beings.”

(330FG1, page 6)

Lamarckian views that organisms change within a lifetime because of need, and that these acquired characteristics can be passed onto their offspring, were common. These included the previously mentioned examples of fish and seal who follow boats or sea lions who learn to go to markets for food. Other examples suggest even greater confusion over how organisms change and how inheritable information is passed onto offspring:

3020116: “Um when like monkeys or apes, like when they find something that they need to do, so they need to change. So, to like stay alive, and then it was feed it into their children and then clearly adapt to the new environment they live in.”

(302FG1, page 8)

Modern human evolution was also a topic where, as already identified, there was much interest, but students responses were often confused and it was not clear whether students really understood what they meant to say. A number of students give evidence of evolution such as humans getting bigger and living longer. Usually, when questioned further about this, the student or one of their peers was able to offer a different explanation and the original student realised that their example was not actually evolution. Humans descending directly from monkey or ape species that are extant today was another commonly held view.

It is doubtful whether teachers are aware of their students' views, or even if they are, whether they have the time and/or resources to affect these. Activities related to challenging misconceptions such as these will be discussed within Chapter 9.

7.3 Comparisons between focus groups

All focus groups were unique and offered different opinions from the students involved. Although no quantitative methods have been used to compare different focus groups or schools, a number of differences were apparent between groups. These are briefly discussed here.

7.3.1 Schools

The one faith school where a focus group took place stood out for the heated discussion around science and religion. Although religion was mentioned in a number of other focus groups in various ways, there was nowhere else where quite such strong opinions and conviction were expressed by students.

Generally those students with the same teacher seem to remember similar activities and lessons although there was some variation and interesting

interactions between students involved in the focus groups. Particular schools were memorable, such as 328, for the variety of examples of evolution that students were able to discuss, including evolution in bacteria, sickle cell anaemia in humans as well as fossils, peppered moths and rock pocket mice. All students seemed very accepting of evolution. This school was also notable for the links students made between genetics and evolution from the very start of the focus group.

7.3.2 Ability sets

All classes involved in this project have been categorised as higher ability students, however there was much variation between students with some groups consisting of top set classes, and others featuring students from middle sets who were predicted C grades. Generally the lower the academic ability of the group, the less willing students were to engage in discussion on evolution. They did not remember so much about their lessons and appeared to have less interest in evolution (although this was not true for all students). With one focus group in particular, many students initially seemed to have very limited knowledge of or interest in evolution and some students could not remember studying evolution at all. However, after the focus group recording was stopped, the students did engage in a very interesting discussion on evolution and genetics. The students were particularly interested in how genetic testing might potentially impact them in the future, e.g. discovering if they were carriers for particular diseases. Finding ways of interesting and engaging students in these topics is important.

7.3.3 Age

The youngest students involved in the focus groups were Year 9 students and the oldest were in Year 12. There were not many obvious differences between students of different ages. The vast majority of students involved in the focus groups were able to speak maturely and quite confidently about their understanding and views of evolution.

Some A level students generally knew more examples of evidence for evolution including archaeopteryx, “similar” (homologous) limb structures, comparative DNA, and embryology, but given that these students were all studying A Level

biology, this was to be expected. These older students were also able to describe the relationship between evolution and genetics in terms of mutations (although the same was true of some younger students). Although these students did think that understanding about genetics helped their understanding of evolution, they felt that they had only learnt about this recently, during their A Level studies, and did not think that this would have helped them when they were younger and working towards their GCSE exams. They thought that it was too complicated and they might not have had the knowledge when they were younger. These older students were able to give perspective over a longer timespan. They found that having learnt about evolution earlier on during secondary school helped their understanding at their current AS Level of study, even if what they had learnt previously was quite basic.

7.4 Comparisons with student questionnaire data

The focus groups did appear to reflect student responses from the questionnaire. Those students who said they were accepting of evolution tended to score higher in the evolution acceptance section of the questionnaire. Those students who were less accepting of evolution did not score so highly. This is interesting from the perspective of validating the questionnaire further. However, care should be taken not to place too much meaning on this, due to the relatively low numbers of students involved in the focus groups and the limited variation in ability level (i.e. no students from classes categorised as lower ability were involved). Additionally, quantitative analysis is not the purpose of these focus groups.

The aim of the focus groups was to gain better understanding of why students gave particular responses within the questionnaire. Although caution should therefore be taken before generalising these findings, they do suggest some interesting reasons behind the results reported, particularly in relation to evolution acceptance. Students who were less accepting of evolution tended to hold strong religious beliefs. However, that is not to say that all students who followed a particular faith were not accepting of evolution. Many students did not realise the meaning of 'theory' within a scientific context and did not recognise that evolution is testable. This appears to have been reflected in the questionnaire,

where the testability of evolution consistently showed the lowest levels of agreement. Students hold many misconceptions related to evolution by natural selection, which were obvious within the questionnaires.

7.5 Summary and implications for teaching

The focus groups have provided many intriguing answers and discussions. Given the vast amount of qualitative data produced, more detailed analyses of these responses could be conducted. However, within the context of this thesis and the research questions asked, these data have been used to provide a glimpse into the opinions and knowledge of UK secondary school students regarding their evolution education.

It is likely that students will have heard about evolution before they learn about it in secondary school. Their knowledge will vary greatly and is likely to have been influenced by family members, television and media, and possibly primary schools. (Within the next five years, all secondary school students should have received some evolution education in primary school so this situation is likely to change. It will be interesting to see whether this is the case.) Teachers should not assume uniformity of prior knowledge or acceptance.

Most students are interested in evolution and are likely to think it is important to them, if they see the relevance to them. Human evolution appears to be of particular interest. As within all science topics, practical activities tend to be particularly enjoyable and memorable, although these should be scrutinised to ensure learning objectives are met. Evolution is often viewed as a difficult subject to find practical activities for, but students do seem to appreciate lessons that involve a variety of activities, including even simple practical work, video clips, or computer activities.

Most students are accepting of evolution. They appear to have a good basic understanding of the topic, but struggle to explain evolution beyond this. Even those students who are confident of their knowledge and that evidence for evolution exists are unable to give many details or examples. Evidence that

appeared most convincing to students were those types that they could see for themselves, such as fossils and homologous structures, and evolution that happens over a relatively quick time span, such as in bacteria, so that they could actually appreciate evolution on a timescale relevant to them. Examples such as these should be included in evolution education and a wider range of examples utilised. Given students' interest in human evolution, it is surprising that more classroom emphasis is not placed on this.

Most students make links between evolution and genetics: many understand the importance of mutations in natural selection and some find it difficult to describe evolution without mentioning genetics. There is variation in whether these links have been taught in schools. Where related topics, such as resistance in bacteria, are covered in other modules, links between these and evolution and genetics modules are not always made. This would seem an important oversight, especially given the evidence for evolution such topics provide.

Students hold many misconceptions including Lamarckian ideas about inheritance of acquired characteristics and the notion that evolution results in progress. Much confusion relates to human evolution: students commonly speak of humans evolving from apes; they mistake recent changes in human height for evolution; and they are confused about the difference between geological and modern time. These were apparent across nearly all focus groups and are likely to be widespread.

Religion is clearly important for some students, and is therefore likely to also be a consideration for their teachers. Although religious students tended to display lower acceptance than their peers, the students involved in the focus groups all showed interest in learning about evolution. Most adopted an acceptance that, to them, did not appear to contradict their religious views. Knowledge of the stance of religious leaders, such as the Pope, take on evolution may help students to feel more comfortable when learning about evolution. This may be a useful strategy for teachers to consider, particularly if they know they will be teaching evolution to students with strong religious beliefs.

Students from the faith school really seemed to enjoy debating evolution and religion and were not at all apprehensive of putting their points forward. It was very difficult to not allow religious debate to take over the scientific discussion. It is recommended that care should be taken if discussing these topics within a science classroom. Although there is certainly a case for recognising the place of religion as a means of understanding the world, active debates between science and religion are not recommended within science lessons.

When interpreting this information it must be remembered that all of these focus groups were conducted with higher ability students: the majority of these students will be sitting higher tier GCSE examinations and were predicted grades C and above. They also involved students who wanted to participate, which, for the most part, meant students who were interested in discussing evolution. Therefore, findings should not be generalised too greatly. It is also important to recognise that teachers are very restricted by exam board specifications and by teaching time and that any suggestions for teaching activities need to comply with requirements.

Chapter 8. Findings from teacher surveys

Here I discuss findings from a small-scale study to ascertain evolution acceptance, evolution knowledge, and genetics knowledge of science teachers and pre-service teachers. Secondary science teachers have high acceptance of evolution, understanding of evolution and understanding of genetics. The relationship between these is moderate and positive, similar to that seen among students. Pre-service science teachers also have high acceptance of evolution and knowledge of genetics, but less knowledge of evolution. Interestingly, there is no correlation between their understanding of genetics and acceptance of evolution. Correlations between evolution acceptance and understanding, and genetics and evolution knowledge, do exist however. Most teachers surveyed feel confident about teaching evolution; pre-service teachers less so. Many participants would like further support in their teaching of evolution, ideally through resources and better training.

The four previous chapters have focused on student data. We have demonstrated the positive impact that education has for most students and considered other factors that might affect acceptance. We have also shown the weak, positive relationships that exist between evolution acceptance, evolution knowledge, and genetics knowledge. Although the main focus of this research is student acceptance and understanding, the knowledge and views of teachers are clearly implicated too, as highlighted within the literature review. These data are collected to support teachers and trainee teachers and not to undermine their professional status: all interpretations of results are motivated by consideration of if and how teachers and trainee teachers could be better supported in their teaching of evolution and genetics.

In this chapter, teacher and pre-service teacher data from online surveys are discussed. These data are preliminary analyses as part of on-going work and therefore do not include complete interpretations of all aspects of the survey. Data related to evolution acceptance, and evolution and genetics knowledge, are analysed and some comparisons made between these two teacher groups. Teacher

confidence is also considered. We begin with an overview of results from the teacher survey, followed by equivalent results from the pre-service teacher survey.

8.1 Teacher surveys

The teacher surveys are based on existing research instruments and include all questions found within the student questionnaire. A full description of the development of the survey can be found in Chapter 2. Previous research into the use of instruments such as the MATE found items included in this survey were suitable for use with secondary school teachers (e.g. Rutledge and Warden 1999), however analysis of the reliability and validity specific to this survey have also been conducted. The survey is found to be suitable for use with teachers and evolution acceptance items show high internal consistency. Full details of these analyses can be found in the supplementary materials. The teacher survey can be found in Appendix C. Note that results are displayed in the order that they appear in the survey, which is different from the student questionnaire (i.e. evolution knowledge is before genetics knowledge).

8.1.1 Background information

A total of 123 UK secondary school teachers participated in the online teacher survey. 85% of these teachers were from state funded schools and 11% were from independent schools. Just 4% were from academies. Over 70% of respondents had been teaching for more than five years. 7% were in their first year of teaching. 60% were female. 58% of the teachers surveyed described themselves as having no religion. 72% of respondents had a degree in a biology-related subject. (It is assumed that the remaining 28% of teachers studied within a different science degree area: within the UK, most secondary science teachers will be required to teach all three sciences to GCSE-level, regardless of subject speciality.) Most participants remembered learning about evolution during their GCSE and A Level studies or equivalent (69%) and during their degree (61%). Only 10% did not recall learning about evolution during their formal education. (Detailed background information can be found in the supplementary materials.)

8.1.2 Teachers are highly accepting of evolution

Acceptance of evolution is high among secondary science teachers, as can be seen in figure 8.1. The greatest proportion of teachers (58%) show very high acceptance of evolution, and 38% display high acceptance. No teachers show very low acceptance of evolution (using proportional categorisation of acceptance as in Table 4.1 but in accordance with the total number of items on this survey, as explained in the supplementary materials). The overall proportion of teachers who accept evolution is 96%. Only 3% of teachers are unsure, and just 1% of teachers reject evolution (Figure 8.2).

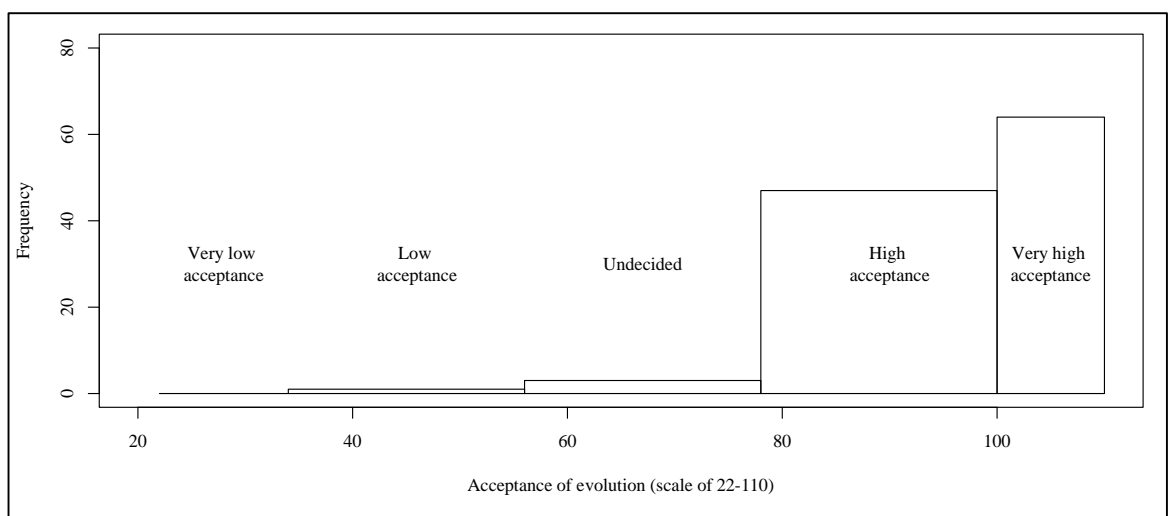


Figure 8.1 Acceptance of evolution among secondary school science teachers (N=115).

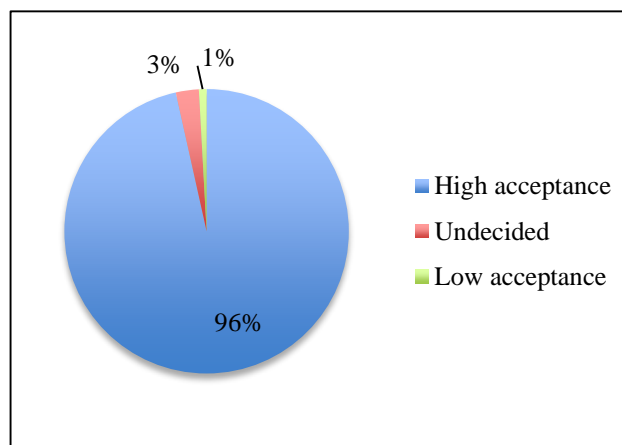


Figure 8.2 Proportion of evolution acceptance among teachers (N=115).

8.1.2.1 Teachers accept different aspects of evolution

Teachers have high acceptance of all seven aspects of evolution, however there is some variation between these, as shown in Figure 8.3. The view of the scientific community is the most accepted concept (95%). Evolution as an explanation for modern life, human evolution, evidence, and geological time are also accepted by at least 90% of teachers. Humans and dinosaurs have the lowest proportion of acceptance, but this is still high at 86%. This also receives the highest proportion of uncertainty (10%). The validity of evolution receives the greatest proportion of rejection (5% of teachers). Perhaps of most concern is the proportion of teachers who are undecided about the evidence for evolution (7.5%) and those who reject the evidence for evolution (2.5%).

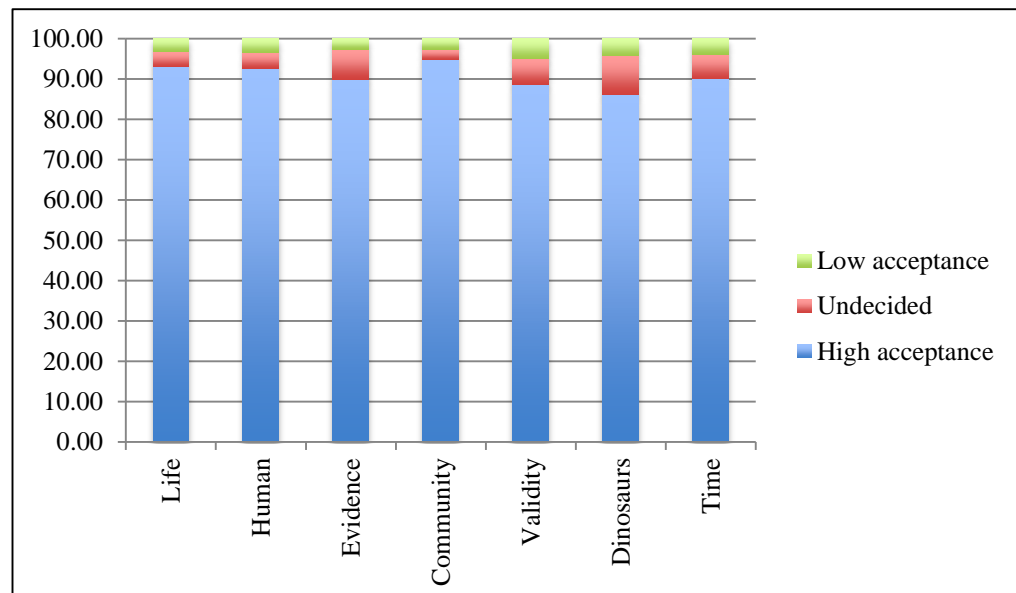


Figure 8.3 Acceptance of different aspects of evolution among teachers (N=115).

8.1.3 Teachers have good understanding of evolution

Most teachers have a good understanding of evolution, as shown in Figure 8.4. The average (mean) score is 12.3 or 82% correct. Four teachers answered all questions correctly. The small number of teachers who appeared to have scored badly (less than five correct answers) corresponds with teachers who did not complete this section of the survey.

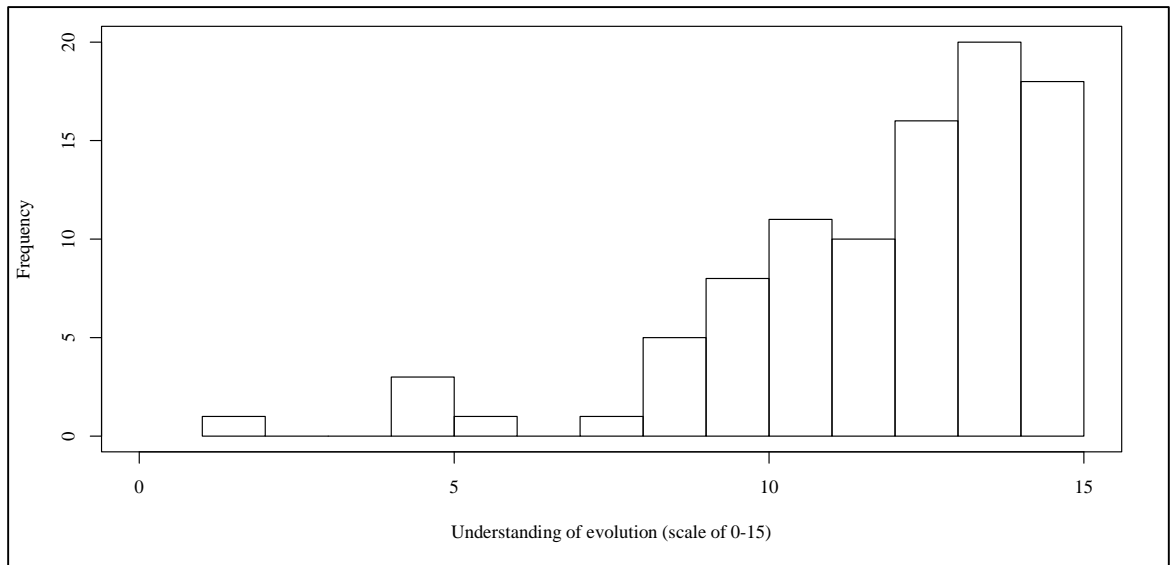


Figure 8.4 Understanding of evolution among secondary school science teachers (N=94).

The proportion of correct answers for each question is shown in Table 8.1. All questions were answered correctly by over 65% of teachers with knowledge of all but two questions being categorised as ‘good’. Teachers appear knowledgeable about variation and natural selection, with very few alternative answers. However, a number of common misconceptions were found in the survey. Although 79% of teachers recognise that evolution involves genetic changes in time, 11% think evolution involves the change of simple to complex organisms and 7% think evolution is the development of characteristics in response to need (Q17). There was also confusion as to when life first appeared on earth (Q22): 13% of teachers thought life had first appeared considerably more recently that it did. Teachers appeared to struggle most with the processes of evolution (Q21): 16% thought natural selection was “a possible but unproven mechanism of evolution”.

Overall these findings suggest that teachers have good subject knowledge. This is often beyond what is expected from most GCSE exam specifications. However, given that the majority of these teachers are biology specialists and *should* have adequate knowledge of evolution, it is worrying that a small proportion of teachers demonstrate confusion over key aspects of evolution.

| Question | Area | Correct (%) | Knowledge | Alternative answer(s) |
|----------|-------------------------|-------------|-----------|--|
| Q12 | Variation | 97.94 | Good | Organisms appear identical on the outside; organisms share no characteristics with others |
| Q11 | Limited survival | 91.75 | Good | Physical fighting between individuals and the strongest ones win |
| Q20 | Natural selection | 91.49 | Good | Inheritance of acquired characteristics |
| Q18 | Natural selection | 89.36 | Good | Lack of knowledge of natural selection, particularly differential reproduction |
| Q15 | Origin of variation | 87.63 | Good | Mutations are intentional; mutations are adaptive responses to specific environmental agents |
| Q19 | Human evolution | 85.11 | Good | Humans have evolved from apes |
| Q23 | Homologous structures | 81.91 | Good | Lack of knowledge of homologous structures |
| Q17 | Definition | 78.72 | Good | Development of characteristics in response to need; change of simple to complex organisms |
| Q22 | Geological time | 78.72 | Good | Lack of knowledge of geological time |
| Q13 | Variation inherited | 78.35 | Good | When a trait is no longer beneficial for survival, the offspring will not inherit the trait |
| Q14 | Differential survival | 76.29 | Good | Fitness is equated with strength, speed, intelligence or longevity |
| Q16 | Origin of species | 76.29 | Good | Organisms can intentionally become new species over time |
| Q24 | Adaptation | 75.53 | Good | Confusion over evolutionary relationships between mammals and fish |
| Q10 | Natural resources | 71.13 | Medium | Organism can always obtain what they need to survive |
| Q21 | Mechanisms of evolution | 67.02 | Medium | Inheritance of acquired characteristics |

Table 8.1 Evolution knowledge of teachers (N=97). As used in Chapters 4-6, knowledge is classified as ‘good’ where over 75% of teachers answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. All questions except 23 and 24 are multiple choice with four possible answers. The probability of getting the right answer by chance is therefore 25%. Questions 23 and 24 contain five possible answers and the probability of gaining the correct answer by chance for these questions is therefore 20%. Alternative answers from questions 10 to 16 are adapted from Bishop *et al.* (2002).

8.1.4 Teachers have good understanding of genetics

Most teachers have a very good knowledge of genetics, as can be seen in Figure 8.5. The average (mean) score is 32 or 94% correct. Two teachers answered all questions correctly.

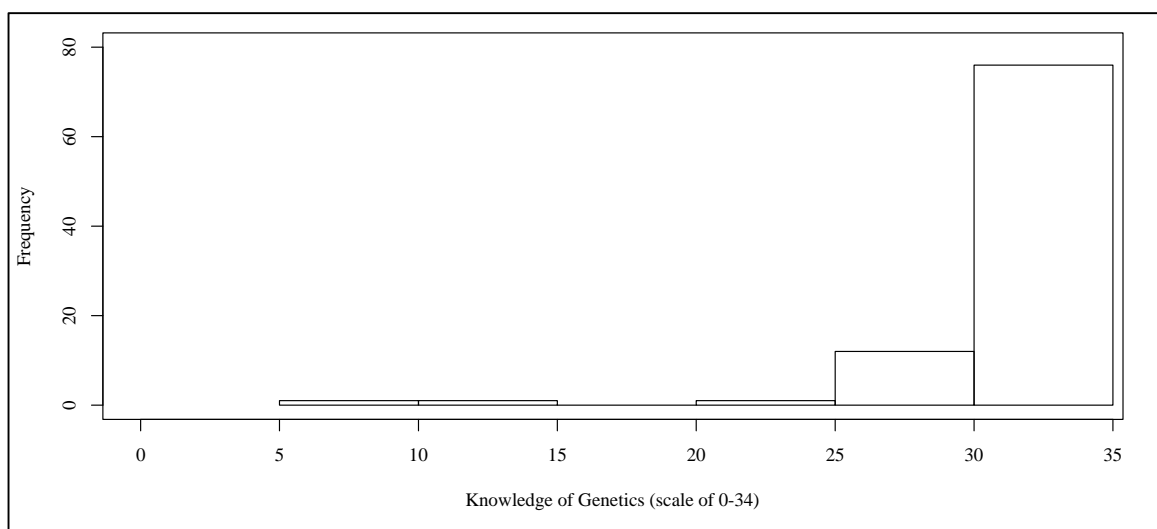


Figure 8.5 Understanding of genetics among secondary school science teachers (N=91).

The proportion of correct answers for each question is shown in Table 8.2. All questions were answered correctly by over 70% of teachers with knowledge for all but one question categorised as ‘good’. As should be expected, teachers had good understanding of ‘living organisms’, with the exception of viruses (Q27): over 26% of teachers thought that viruses are living organisms (Q27f). There was also some confusion over whether bacteria were made of cells (Q27q) with 24% of teachers responding that they weren’t. 24% of teachers were unable to correctly identify the sequential relationship between structures (Q26). Apart from these, there are no obvious areas demonstrating lack of knowledge, as would be hoped for from teachers.

| Question | Area | Correct (%) | Knowledge | Alternative answer (s) |
|----------|-------------------------------|-------------|-----------|---|
| Q27a | Living organisms: humans | 100.00 | Good | - |
| Q27l | Animals: virus | 100.00 | Good | - |
| Q27b | Living organisms: giraffes | 98.90 | Good | Giraffes are not living organisms |
| Q27c | Living organisms: moths | 98.90 | Good | Moths are not living organisms |
| Q27d | Living organisms: oak tree | 98.90 | Good | Oak trees are not living organisms |
| Q27m | Cells: humans | 98.90 | Good | Humans are not made up of cells |
| Q27s | Genetic information: humans | 98.90 | Good | Humans do not contain genetic information |
| Q27e | Living organisms: bacteria | 97.80 | Good | Bacteria are not living organisms |
| Q27g | Animals: humans | 97.80 | Good | Humans are not animals |
| Q27h | Animals: giraffes | 97.80 | Good | Giraffes are not animals |
| Q27n | Cells: giraffes | 97.80 | Good | Giraffes are not made up of cells |
| Q27o | Cells: moths | 97.80 | Good | Moths are not made up of cells |
| Q27p | Cells: oak tree | 97.80 | Good | Oak trees are not made of cells |
| Q27t | Genetic information: giraffes | 97.80 | Good | Giraffes do not contain genetic information |
| Q27v | Genetic information: oak tree | 97.80 | Good | Oak trees do not contain genetic information |
| Q31 | Genetic engineering | 97.80 | Good | Confusion between genetic engineering and cloning |
| Q28e | Asexual | 97.78 | Good | Definition/meaning of word |
| Q27u | Genetic information: moths | 96.70 | Good | Moths do not contain genetic information |
| Q27w | Genetic information: bacteria | 96.70 | Good | Bacteria do not contain genetic information |
| Q27k | Animals: bacteria | 95.60 | Good | Bacteria are animals |
| Q27j | Animals: oak tree | 94.51 | Good | Oak trees are animals |
| Q27x | Genetic information: virus | 94.51 | Good | Viruses do not contain genetic information |
| Q30 | Plant reproduction | 94.51 | Good | Plants reproduce asexually |
| Q28d | Gamete | 94.44 | Good | Definition/meaning of word |

| Question (cont.) | Area | Correct (%) | Knowledge | Alternative answer (s) |
|-------------------------|-------------------------|--------------------|------------------|---|
| Q28c | Clone | 93.41 | Good | Definition/meaning of word |
| Q28b | Mutation | 92.22 | Good | Definition/meaning of word |
| Q29 | Cell function | 91.21 | Good | Different types of cells contain different kinds of genes |
| Q28a | Alleles | 90.00 | Good | Definition/meaning of word |
| Q27i | Animals: moths | 87.91 | Good | Moths are not animals |
| Q27r | Cells: virus | 82.42 | Good | Viruses are not made of cells |
| Q28f | Genetic | 81.11 | Good | Definition/meaning of word |
| Q26 | Size sequence | 75.82 | Good | Confusion of relationship between chromosomes and genes |
| Q27q | Cells: bacteria | 75.82 | Good | Bacteria are not made of cells |
| Q27f | Living organisms: virus | 73.63 | Medium | Viruses are living organisms |

Table 8.2 Genetics knowledge of teachers (N=91). Knowledge is classified as ‘good’ where over 75% of teachers answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. It should also be noted that questions 29, 30 and 31 are multiple choice questions with four possible answers. The probability of getting the right answer by chance is therefore 25%. The remaining questions are variations on the multiple choice question but have varying numbers or combinations of possible answers.

8.1.5 Relationships between acceptance and understanding

Similar, moderate, positive correlations are observed between acceptance of evolution and knowledge of genetics ($R_s = 0.43, p < .001$), knowledge of genetics and knowledge of evolution ($R_s = 0.46, p < .001$), and acceptance of evolution and understanding of evolution ($R_s = 0.42, p < .001$). These relationships are shown in Figures 8.6, 8.7 and 8.8. This clearly shows that relationships do exist between evolution acceptance, and genetics and evolution knowledge. However, it is curious that even for teachers who, as we have learnt, have good knowledge of these topics and high acceptance of evolution, these relationships are not stronger. Partial correlations reveal weak relationships between evolution acceptance and genetics knowledge, given evolution knowledge ($R_s = 0.30, p = .002$) and evolution acceptance and evolution knowledge, controlling for genetics knowledge ($R_s = 0.28, p = .004$).

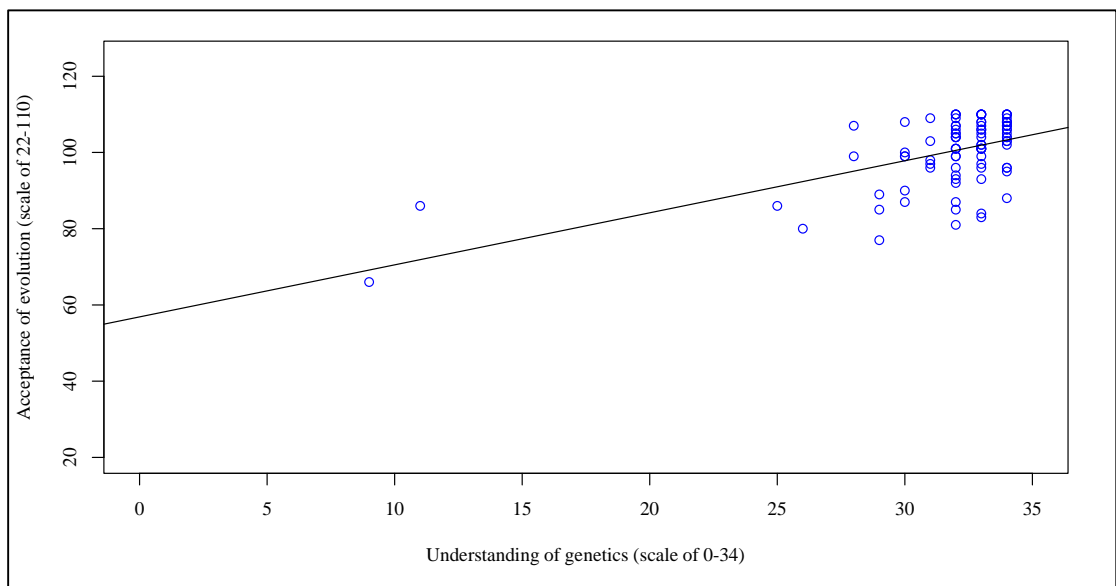


Figure 8.6 Evolution acceptance and understanding of genetics among secondary school science teachers (N=91).

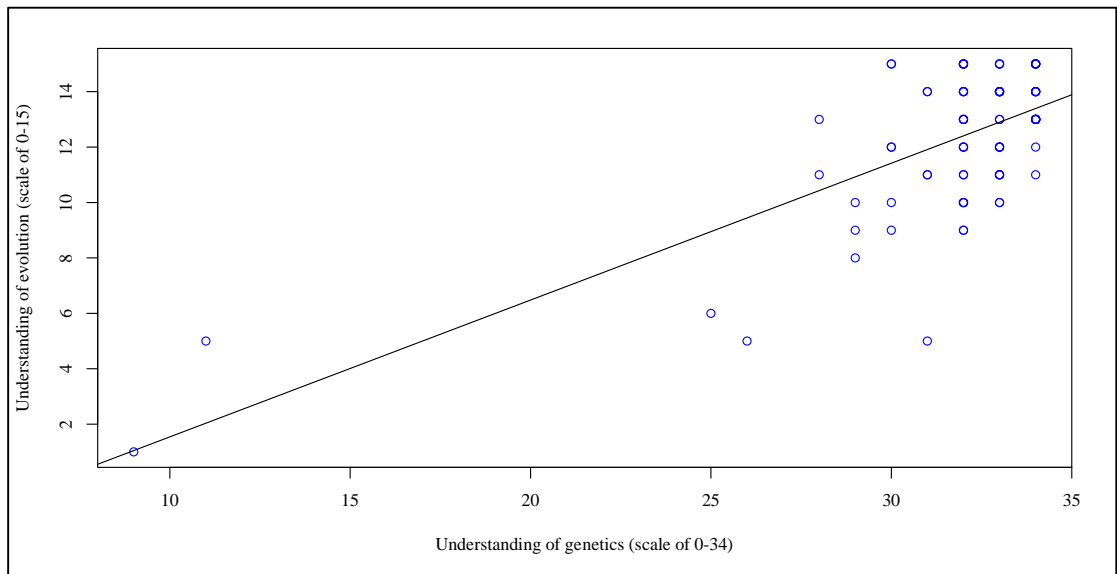


Figure 8.7 Understanding of evolution and understanding of genetics among secondary school science teachers (N=91)

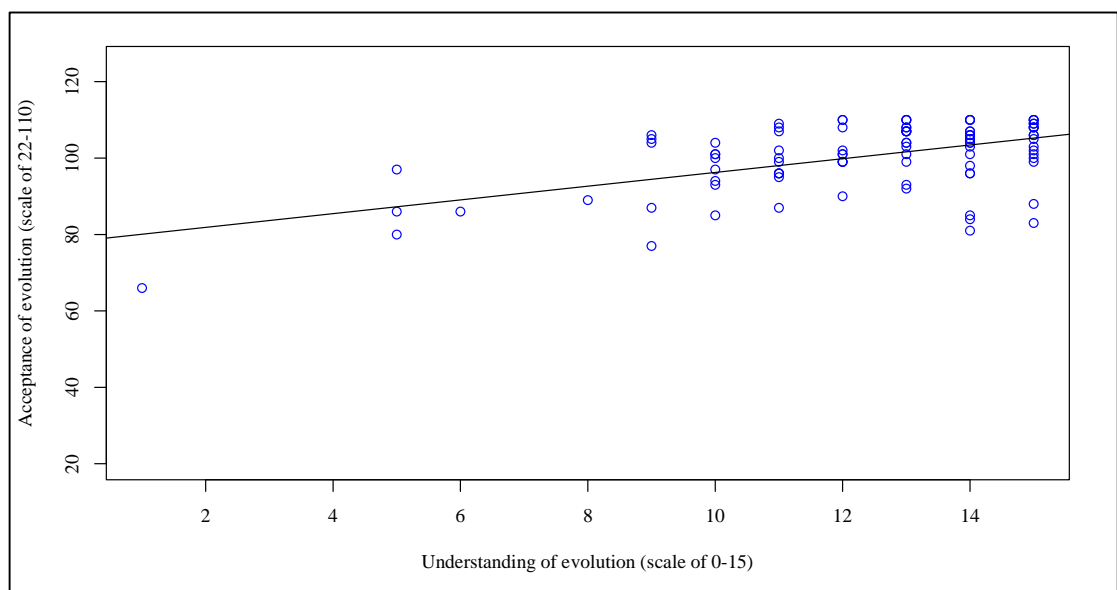


Figure 8.8 Acceptance of evolution and understanding of evolution among secondary school science teachers (N=94)

8.1.6 Teachers are confidence about teaching evolution

In order to gauge confidence in teaching evolution, teachers were asked how confident they felt teaching science generally, and also evolution. As can be seen in Figure 8.9, the majority of teachers are confident about teaching evolution: 43% state they are ‘really confident’, and 38% are confident. Teachers tend to be slightly less confident about teaching evolution than they do science in general (90% are either confident or really confident). These findings should not come as a surprise, given the relatively high understanding of evolution demonstrated earlier in the chapter. Nonetheless, teachers are keen to have further support in their teaching. 82% of teachers who completed the survey indicate that they would like additional teaching resources. Other types of support that teachers would like to receive included web-based information (59%), discussion with other teachers (20%) and INSET training (20%). Only 12% stated that they felt they did not need any support. Ways in which teachers can be better supported, particularly those who are less confident, shall be discussed in Chapter 9.

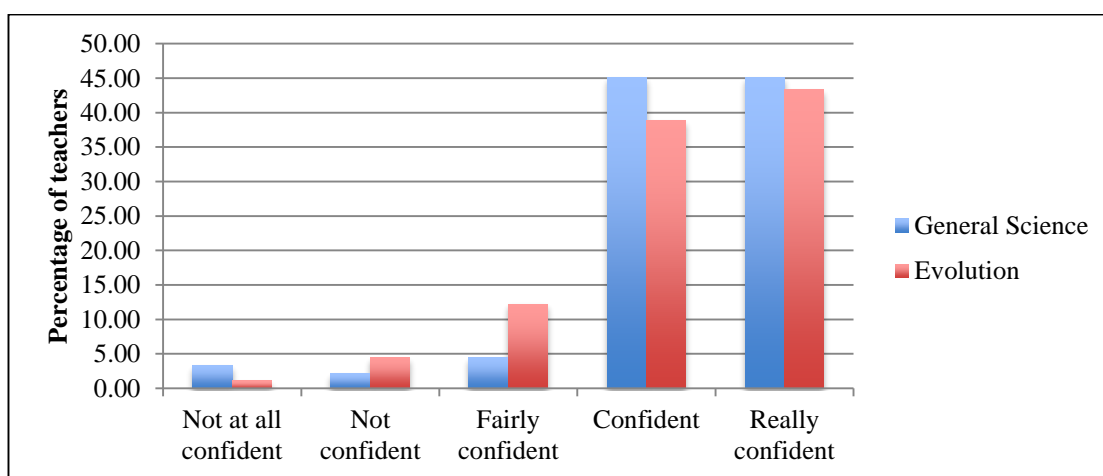


Figure 8.9 Secondary science teachers' confidence in teaching general science and in teaching evolution (N=91).

In summary, secondary school science teachers are highly accepting of evolution. They have good knowledge of evolution and genetics, however a small proportion demonstrate misconceptions or confusions. There is clearly a relationship between evolution and genetics, but whether knowledge of genetics is causative of acceptance or understanding of evolution is unclear. The majority of secondary

school teachers are confident about teaching science and evolution. However, the very self-selecting nature of the survey should be taken into account when interpreting these results.

8.2 Pre-service teacher surveys

As with the teacher surveys, a full description of the development of the survey can be found in Chapter 2. Analysis has found the survey to be suitable for use with pre-service teachers and details of this can be found in the supplementary materials. The pre-service teacher survey can also be found in Appendix C. (Some background information questions are different from those found in the teacher survey to ensure they are relevant to trainee, rather than practising teachers, but otherwise the survey is the same as that completed by teachers.)

8.2.1 Background information

50 UK pre-service secondary school teachers participated in the online survey. They came from 17 different universities in England, Scotland, Northern Ireland, and Wales. All were studying for PGCE qualifications in Secondary Science or in a specific science subject. All surveys were completed between April and June 2015. This is towards the end of the UK academic year and therefore trainee teachers should have been near the end of their training. 62% were female and 58% described themselves as having no religion. 62% of respondents had a degree in a biology-related subject. (It is assumed that the remaining 38% of trainee teachers studied within a different science degree area but are now training to teach all three sciences to GCSE-level, regardless of subject speciality.) Most participants remembered learning about evolution during their GCSEs (70%) and A Level exams or equivalent (58%) and during their degree (40%). 12% did not recall learning about evolution during their formal education. (Detailed background information can be found in the supplementary materials.)

8.2.2 Pre-service teachers are highly accepting of evolution

Trainee science teachers are very accepting of evolution, as can be seen in Figure 8.10. Half of pre-service teachers show very high acceptance of evolution, and 46% display high acceptance. No teachers show low or very low acceptance of evolution. The overall proportion of trainee teachers who accept evolution is 96%. The remaining 4% are unsure (Figure 8.11).

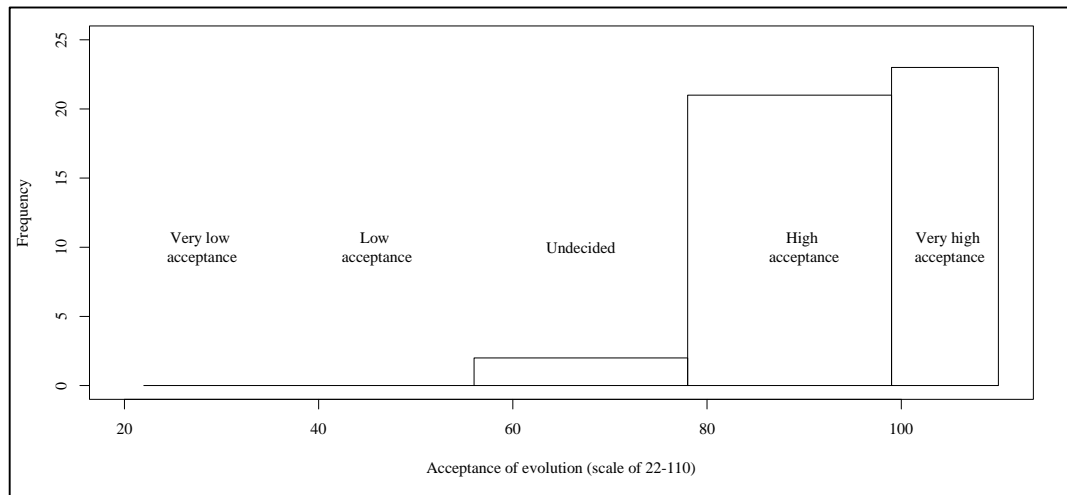


Figure 8.10 Acceptance of evolution among pre-service secondary school science teachers (N=46).

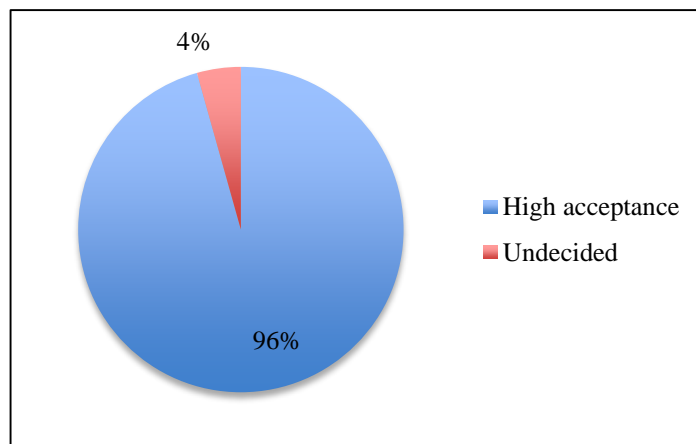


Figure 8.11 Proportion of evolution acceptance among pre-service teachers (N=46).

8.2.2.1 Pre-service teachers accept different aspects of evolution

Trainee teachers have high acceptance of all seven aspects of evolution, and there is relatively little variation between these, as shown in Figure 8.12. Evolution as an explanation for life (92.6%) and the view of the scientific community (92.4%) are the most accepted concepts. Humans and dinosaurs have the lowest proportion of acceptance, but this is still high at 86%. Evidence for evolution, the validity of evolution as a scientific theory, and humans and dinosaurs receive the highest proportion of uncertainty (9%). Human evolution has the greatest proportion of rejection (6.5%).

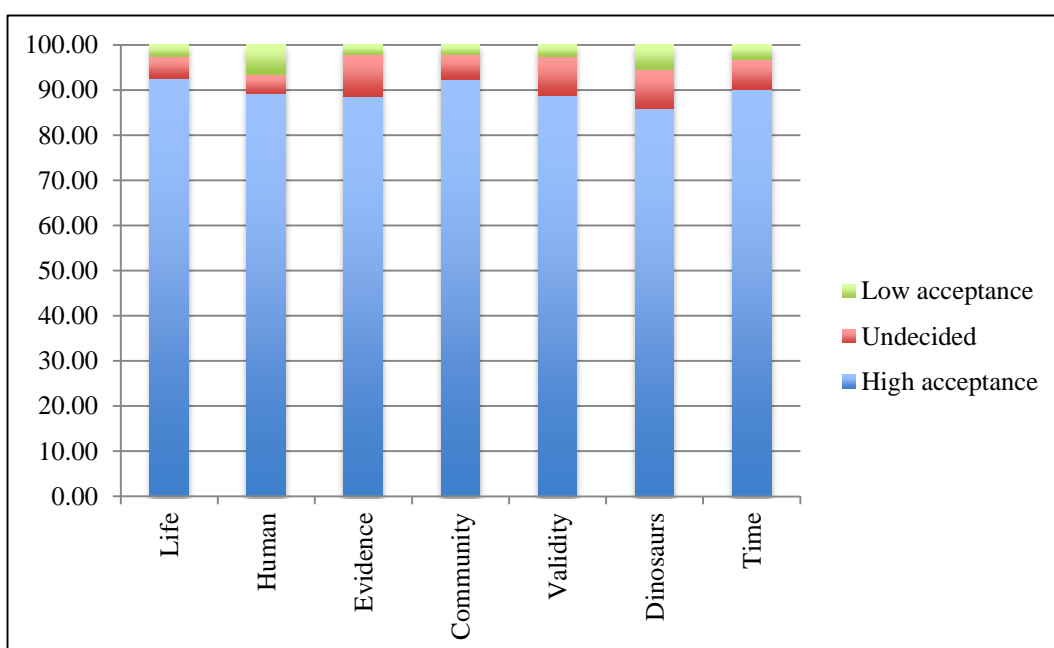


Figure 8.12 Acceptance of different aspects of evolution among pre-service teachers (N=46).

8.2.3 Pre-service teachers have some understanding of evolution

There is much variation in pre-service teachers' knowledge of evolution. Most trainee teachers have some understanding of evolution, as shown in Figure 8.13. The average (mean) score is 10.7 or 71% correct. Two pre-service teachers answered all questions correctly.

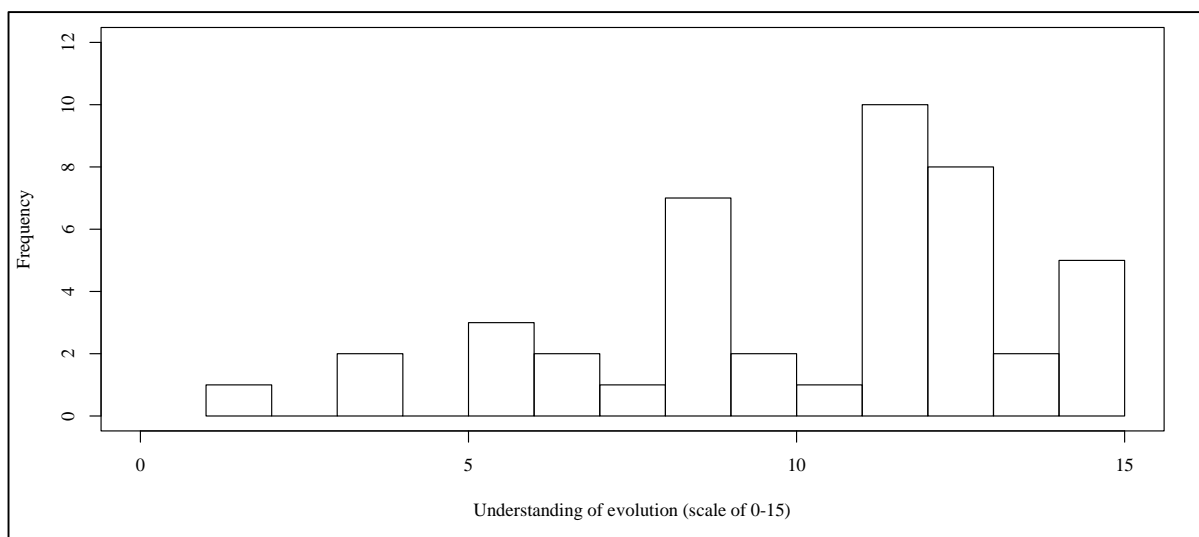


Figure 8.13 Understanding of evolution among pre-service secondary school science teachers (N=44).

The proportion of correct answers for each question is shown in Table 8.3. All questions were answered correctly by over by over 50% of participants. Knowledge of six questions are categorised as ‘good’ and nine are categorised as ‘medium’. Trainee teachers appear knowledgeable about variation, human evolution, adaptation and some aspects of natural selection. However, there appeared confusion about many concepts and a number of common misconceptions were detected. Although 66% of pre-service teachers recognise that evolution involves genetic changes in time, 27% think evolution involves the change of simple to complex organisms and 7% think evolution is the development of characteristics in response to need (Q16). Only 59% of participants were able to identify that “modifications an organism acquires during its lifetime” are not part of the theory of evolution by natural selection (Q17) and 25% thought that natural selection is “the inheritance of acquired characteristics” (Q20). Pre-service teachers struggled most with geological time and when life first appeared on earth (Q21). Only 52% were able to answer the question correctly with 32% thinking life had first appeared considerably more recently.

The frequency of these alternative answers are quite concerning and suggest that trainee teachers do not have the knowledge required to competently teach evolution. Although some of these questions do go beyond the scope of the

average GCSE-level syllabus, it is worrying that misconceptions prevail. However, it must be remembered that not all of the pre-service teachers who completed this questionnaire are biology specialists. Indeed, only 40% recall learning about evolution during their degree programme. No information is known about how recently these pre-service teachers completed their undergraduate or other degree courses. For some it is possible that many years have passed since last studying evolution (and 12% do not even remember learning about evolution formally). Regardless of whether students have studied evolution previously, it is clear that their recent trainee teaching experiences have not provided them with knowledge of evolution that might be expected of science teachers.

| Question | Area | Correct (%) | Knowledge | Alternative answer(s) |
|----------|-------------------------|-------------|-----------|--|
| Q11 | Variation | 93.18 | Good | Organisms appear identical on the outside; organisms share no characteristics with others |
| Q10 | Limited survival | 84.09 | Good | Physical fighting between individuals and the strongest ones win |
| Q18 | Human evolution | 84.09 | Good | Humans have evolved from apes |
| Q12 | Variation inherited | 79.55 | Good | When a trait is no longer beneficial for survival, the offspring will not inherit the trait |
| Q19 | Natural selection | 79.55 | Good | Inheritance of acquired characteristics |
| Q23 | Adaptation | 75.00 | Good | Confusion over evolutionary relationships between mammals and fish |
| Q22 | Homologous structures | 72.73 | Medium | Lack of knowledge of homologous structures |
| Q9 | Natural resources | 68.18 | Medium | Organism can always obtain what they need to survive |
| Q14 | Origin of variation | 68.18 | Medium | Mutations are intentional; mutations are adaptive responses to specific environmental agents |
| Q13 | Differential survival | 65.91 | Medium | Fitness is equated with strength, speed, intelligence or longevity |
| Q16 | Definition | 65.91 | Medium | Development of characteristics in response to need; change of simple to complex organisms |
| Q15 | Origin of species | 61.36 | Medium | Organisms can intentionally become new species over time |
| Q20 | Mechanisms of evolution | 61.36 | Medium | Inheritance of acquired characteristics |
| Q17 | Natural selection | 59.09 | Medium | Lack of knowledge of natural selection, particularly differential reproduction |
| Q21 | Geological time | 52.27 | Medium | Lack of knowledge of geological time |

Table 8.3 Evolution knowledge of pre-service teachers (N=44). As used in Chapters 4-6, knowledge is classified as ‘good’ where over 75% of teachers answer the question correctly; between 25%-75% is ‘medium’, and less than 25% is ‘poor’. All questions except 22 and 23 are multiple choice with four possible answers. The probability of getting the right answer by chance is therefore 25%. Questions 22 and 23 contain five possible answers and the probability of gaining the correct answer by chance for these questions is therefore 20%. Alternative answers from questions 9 to 15 are adapted from Bishop *et al.* (2002).

8.2.4 Pre-service teachers have good understanding of genetics

All pre-service science teachers have a good knowledge of genetics, as seen in Figure 8.14. The average score is 31 or 91% correct. No participants have scores lower than 25 and two answered all questions correctly.

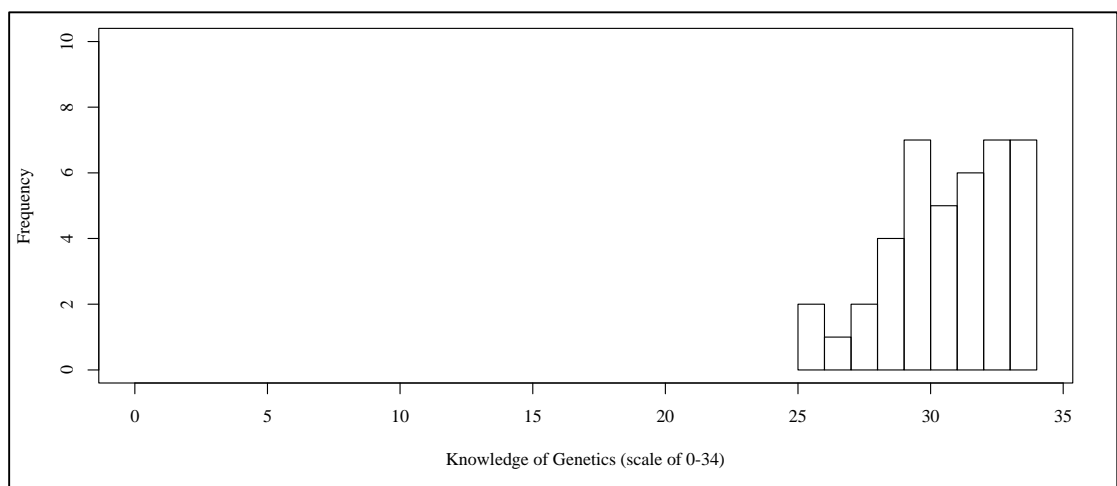


Figure 8.14 Understanding of genetics among pre-service secondary school science teachers (N=41).

The proportion of correct answers for each question is shown in Table 8.4. All questions were answered correctly by over 60% of pre-service teachers with knowledge for all but three questions categorised as ‘good’. Participants had good understanding of ‘living organisms’, with many questions being answered correctly by all trainee teachers (Q26). Questions related to viruses caused some confusion: over 39% of trainee teachers thought that viruses are living organisms (Q26f) and 24% thought that viruses were made of cells (Q26r). There was also some confusion over whether bacteria were made of cells (Q26q) with 29% of trainee teachers responding that they weren’t. 34% of pre-service teachers were unable to correctly identify the sequential relationship between structures (Q25). All other questions were answered correctly by over 80% of trainee teachers and there are few other areas of concern.

| Question | Area | Correct (%) | Knowledge | Alternative answer (s) |
|----------|-------------------------------|-------------|-----------|---|
| Q26a | Living organisms: humans | 100.00 | Good | - |
| Q26b | Living organisms: giraffes | 100.00 | Good | - |
| Q26c | Living organisms: moths | 100.00 | Good | - |
| Q26d | Living organisms: oak tree | 100.00 | Good | - |
| Q26e | Living organisms: bacteria | 100.00 | Good | - |
| Q26h | Animals: giraffes | 100.00 | Good | - |
| Q26l | Animals: virus | 100.00 | Good | - |
| Q26m | Cells: humans | 100.00 | Good | - |
| Q26n | Cells: giraffes | 100.00 | Good | - |
| Q26o | Cells: moths | 100.00 | Good | - |
| Q26p | Cells: oak tree | 100.00 | Good | - |
| Q26s | Genetic information: humans | 100.00 | Good | - |
| Q26t | Genetic information: giraffes | 100.00 | Good | - |
| Q26u | Genetic information: moths | 100.00 | Good | - |
| Q26g | Animals: humans | 97.56 | Good | Humans are not animals |
| Q26j | Animals: oak tree | 97.56 | Good | Oak trees are animals |
| Q26v | Genetic information: oak tree | 97.56 | Good | Oak trees do not contain genetic information |
| Q26w | Genetic information: bacteria | 97.56 | Good | Bacteria do not contain genetic information |
| Q26k | Animals: bacteria | 95.12 | Good | Bacteria are animals |
| Q27e | Asexual | 95.12 | Good | Definition/meaning of word |
| Q30 | Genetic engineering | 92.68 | Good | Confusion between genetic engineering and cloning |
| Q26x | Genetic information: virus | 90.24 | Good | Viruses do not contain genetic information |
| Q27b | Mutation | 90.24 | Good | Definition/meaning of word |
| Q27d | Gamete | 90.24 | Good | Definition/meaning of word |

| Question (cont.) | Area | Correct (%) | Knowledge | Alternative answer (s) |
|-------------------------|-------------------------|--------------------|------------------|---|
| Q27c | Clone | 87.80 | Good | Definition/meaning of word |
| Q26i | Animals: moths | 82.93 | Good | Moths are not animals |
| Q27f | Genetic | 82.93 | Good | Definition/meaning of word |
| Q27a | Alleles | 80.49 | Good | Definition/meaning of word |
| Q28 | Cell function | 80.49 | Good | Different types of cells contain different kinds of genes |
| Q29 | Plant reproduction | 80.49 | Good | Plants reproduce asexually (not by sexual and asexual reproduction) |
| Q26r | Cells: virus | 75.61 | Good | Viruses are not made of cells |
| Q26q | Cells: bacteria | 70.73 | Medium | Bacteria are not made of cells |
| Q25 | Size sequence | 65.85 | Medium | Confusion of relationship between chromosomes and genes |
| Q26f | Living organisms: virus | 60.98 | Medium | Viruses are living organisms |

Table 8.4 Genetics knowledge of pre-service teachers (N=41). Knowledge is classified as ‘good’ where over 75% of teachers answer the question correctly: between 25%-75% is ‘medium’, and less than 25% is ‘poor’. It should also be noted that questions 28, 29 and 30 are multiple choice questions with four possible answers. The probability of getting the right answer by chance is therefore 25%. The remaining questions are variations on the multiple choice question but have varying numbers or combinations of possible answers.

8.2.5 Relationships between acceptance and understanding

Curiously, no correlation was found between acceptance of evolution and knowledge of genetics ($R_s = 0.04$, $p = .83$). This is a very unexpected result and is shown in Figure 8.15. Moderately strong, positive correlation was detected between knowledge of genetics and knowledge of evolution ($R_s = 0.67$, $p < .001$), and moderate, positive correlation was found between acceptance of evolution and understanding of evolution ($R_s = 0.39$, $p = .01$). These relationships are shown in Figures 8.16 and 8.17. Partial correlations reveal a moderate relationship between evolution acceptance and evolution knowledge, given genetics knowledge ($R_s = 0.50$, $p < .001$) but a negative relationship between evolution acceptance and genetics knowledge, controlling for evolution knowledge ($R_s = -0.33$, $p = .02$). This would appear to suggest that knowledge of genetics has limited impact on evolution acceptance, although the sample size may affect these analyses.

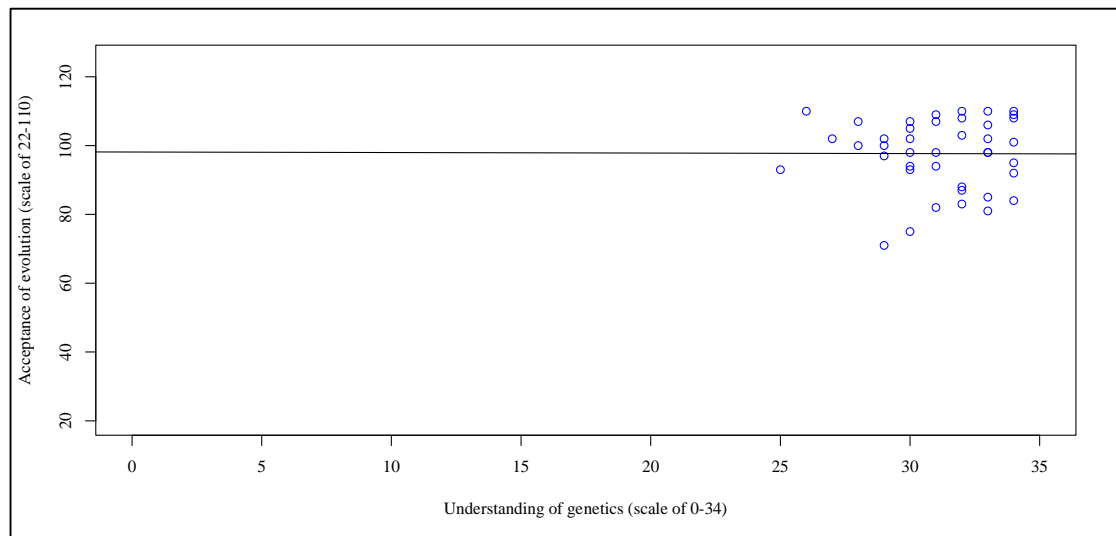


Figure 8.15 Understanding of genetics and acceptance of evolution among pre-service teachers (N=41).

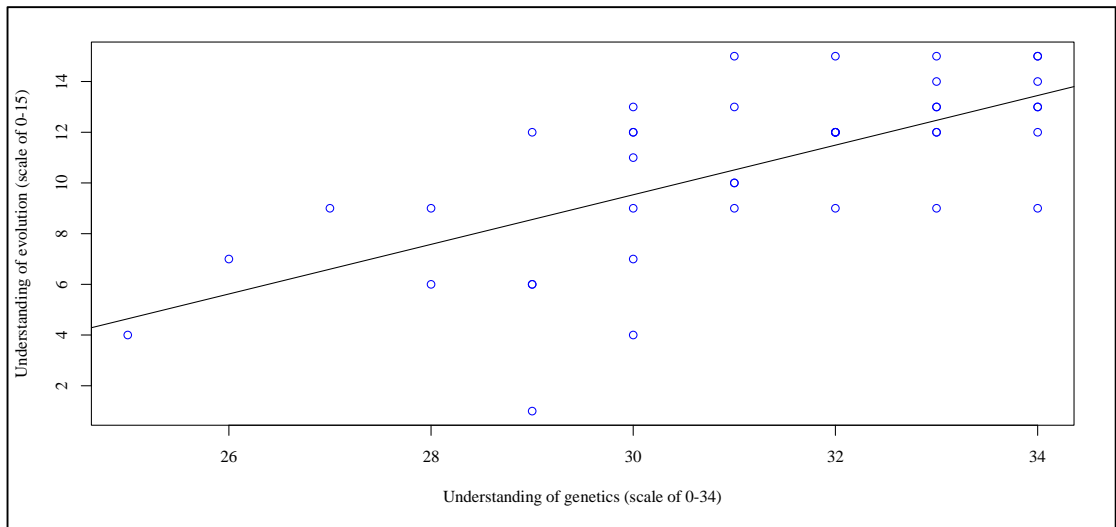


Figure 8.16 Understanding of genetics and understanding of evolution among pre-service teachers (N=41).

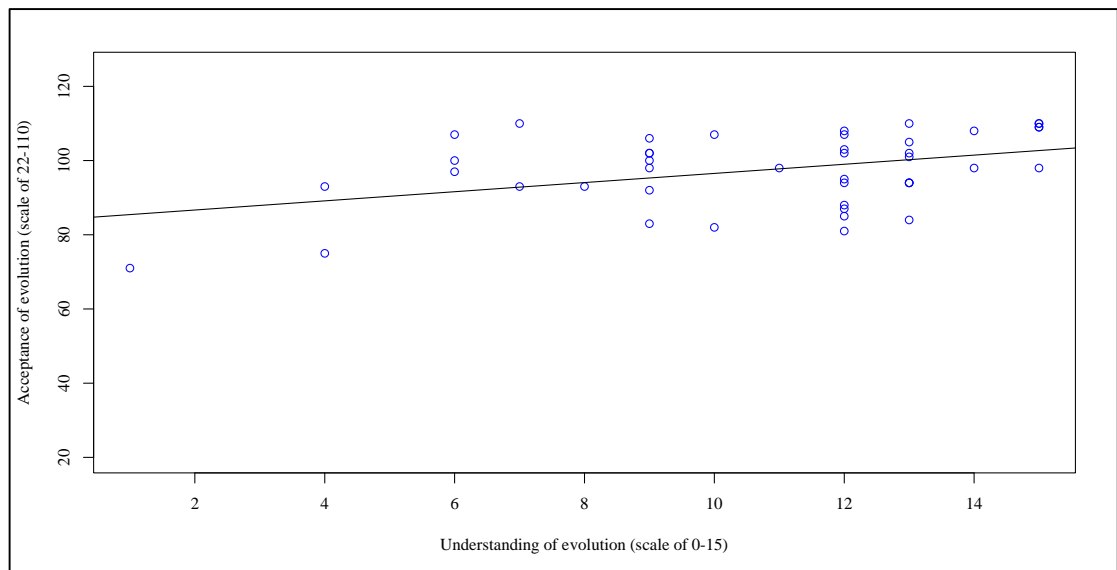


Figure 8.17 Acceptance of evolution and understanding of evolution among pre-service teachers (N=41).

8.2.6 Pre-service teachers are fairly confidence about teaching evolution

As can be seen in Figure 8.18, the majority of trainee teachers are confident about teaching general science: 73% are ‘confident’ and 22% are ‘really confident’. This provides a contrast to their confidence in teaching evolution where the combined proportion of the pre-service teachers who are ‘confident’ or ‘really confident’ is 51%. 37% of participants are only ‘fairly confident’ about teaching evolution, and 12% are ‘not confident’ or ‘not at all confident’. Although this is may be expected, given that these participants have not yet completed their initial teacher training and have limited experience of teaching, it is clear that there is a difference in confidence between general science and evolution.

Perhaps not surprisingly, pre-service teachers are keen to have further support in their teaching. 95% would like additional teaching resources. Other types of support which teachers would like to receive included web-based information (63%), INSET training (27%), and discussion with other teachers (17%). Only 5% did not feel that they needed any support. This shall be discussed further in Chapter 9.

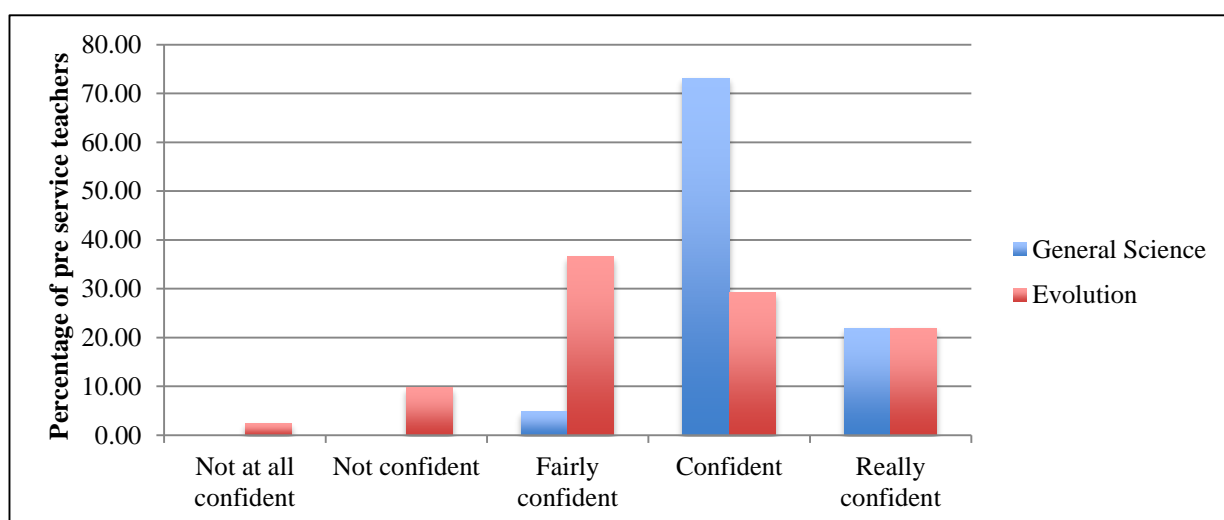


Figure 8.18 Pre-service secondary science teachers’ confidence in teaching general science and in teaching evolution (N=41).

In summary, pre-service secondary school science teachers are highly accepting of evolution. They have good knowledge of genetics, but less understanding of evolution. Surprisingly, there is no relationship between evolution acceptance and genetics knowledge. The reasons behind this peculiar result are unclear, but may be related to a small sample size. Moderate to strong, positive correlations are detected between evolution acceptance and knowledge, and between genetics and evolution knowledge. Although seemingly confident about teaching general science, many trainee teachers are less confident about teaching evolution.

8.3 Comparisons between teachers and pre-service teachers

Teachers and pre-service teachers have high acceptance of evolution. There is no significant difference between their MATE scores ($Z = 2957.5$, $p = .24$). Teachers have significantly higher knowledge of evolution ($Z = 2699.5$, $p = .004$) and genetics ($Z = 2376$, $p = .01$). These are shown in Figure 8.19.

There are moderate to strong, positive correlations between teachers' and pre-service teachers' acceptance and understanding of evolution and genetics, with the obvious exception of evolution acceptance and genetics understanding for trainee teachers, where no correlation is seen. (Incidentally, teacher correlations appear more similar to those discovered in the student questionnaires.) It is not clear why this difference appears.

As might be expected, practising teachers are more confident about teaching science in general, and in teaching evolution, than trainee teachers. The difference between trainee teachers' general science and evolution teaching confidence levels are particularly intriguing and suggest that perhaps, teacher training is not providing adequate support for evolution.

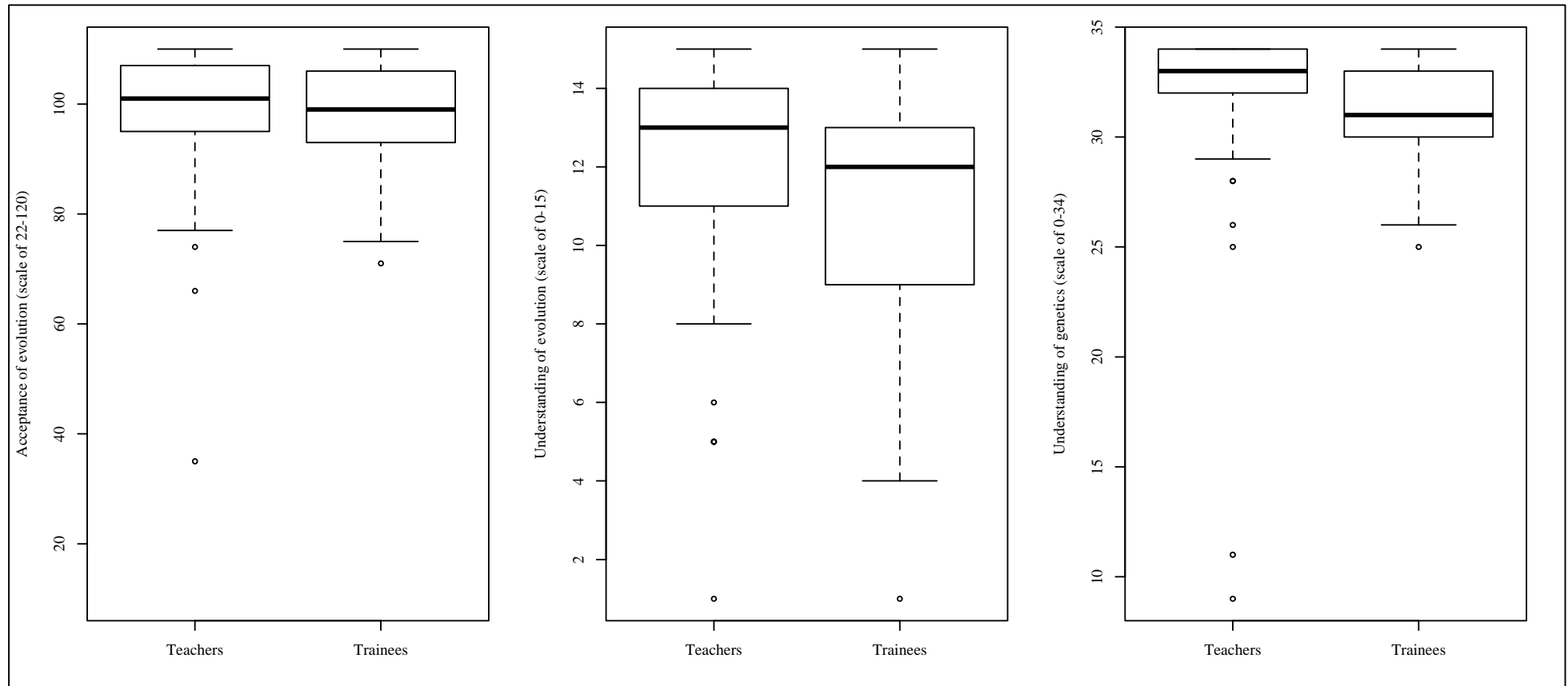


Figure 8.19 Evolution acceptance, evolution understanding, and genetics understanding for teachers and pre-service teacher (evolution acceptance: teacher N=115; trainee teacher N=46; evolution understanding: teacher N=94; trainee teacher N=44; genetics understanding: teacher N=91; trainee teacher N=41).

8.4. Summary and implications for teaching

Reassuringly, evolution acceptance is high among teachers and pre-service teachers. The teachers who completed this survey clearly have a good knowledge of evolution and genetics. Despite this, a number of misconceptions are held, particularly relating to evolution. Teachers appear confident about teaching evolution, but most are still keen to utilise extra support. Trainee teachers generally have good, but significantly less, knowledge of genetics than teachers. They lack understanding of evolution. They are less confident about teaching evolution than teachers and a higher proportion would like more support in their teaching of the topic. There are moderate, positive relationships between teachers' understanding and acceptance of evolution and genetics, similar to those observed among students. Trainee teachers show more diverse relationships but no correlation is found between their acceptance of evolution and understanding of genetics.

A number of questions arise from these results. Firstly, why is teacher knowledge of genetics and, in particular, evolution, better than that of pre-service teachers? Is this typical of trainee teacher subject knowledge during their training and something that will improve as they gain more experience of teaching these topics? Secondly, why are trainee teacher correlations so different from those observed in teachers and students? Are these simply an artefact of sample size, or are there other factors involved? Thirdly, how representative of secondary school teachers are participants in this survey? These surveys have quite small sample sizes, especially for pre-service teachers. It is possible that teachers who completed this survey have a particular interest in evolution and/or are especially dedicated to their profession, given that most teachers completed the survey after following links from education pages on social media sites. Overall, teacher knowledge would appear more than sufficient for teaching GCSE-level biology, such as students involved in the questionnaire will have been learning. However, care must be taken before generalising. This chapter provides an overview of preliminary work into these more teacher-based areas of research into evolution education and it is hoped that the above questions may be answered in the future.

Chapter 9. Teaching resources and outreach

A trial resources package has been developed alongside schools involved in this project. This utilises existing resources, mainly those available freely online, but also includes some new ideas for activities. Feedback has been positive, but not very constructive. There is some provisional evidence to suggest that using the GEVOteach resources does have a positive impact on knowledge of evolution and genetics. There is also evidence to suggest that using a resource which links genetics and evolution, in this case an exercise on natural selection in rock pocket mice, can positively impact understanding and acceptance of evolution. The GEVOteach resources will be updated to include key findings from this research including activities designed to specifically challenge misconceptions. These will build on suggestions and feedback from teachers and students.

Although the GCSE curriculum is quite prescriptive within the UK, the ways in which topics are to be taught are for individual schools and teachers to decide. Teaching resources are the materials that teachers use to deliver the curriculum. There are a wide variety of resource types which include books, video clips, interactive presentations, worksheets, and practical activities. Ideally these encourage students to be actively engaged in their learning.

An aim of this project is to develop and distribute useable, effective teaching resources for evolution and genetics at GCSE-level. Initially the trial resource package was used as a means of encouraging schools to become involved in the project and many teachers were very keen to receive any free resources. However, these resources have been under constant review and will continue to be developed further in light of the findings of this research. Within this chapter, the rationale behind the design and development of the resource package is discussed. Feedback from teachers and students is outlined and provisional data are provided related to the effectiveness of the GEVOteach resources. Improvements and future work for the resource package are considered. University outreach, within the context of this project, is also reviewed. A draft version of the resource package can be found in the supplementary materials.

9.1 Development of the resource pack

There are two reasons why a resources packaged is being developed as part of this research project. Firstly, it became apparent through reviewing literature and discussing evolution education with teachers that there is a lack, or certainly a perceived lack, of quality, effective resources, readily available for teachers and suitable for use immediately within secondary schools. Secondly, in order to interest schools in this research project, having something of use to teachers was clearly going to be advantageous. In developing this resources package it is hoped that collaborative work between evolution and education experts can have a positive impact on evolution education.

The main examination boards in the UK cover basic genetics and evolution as outlined in Chapter 1 and the supplementary materials. Due to the differences between exam board specifications and changes to the GCSE exam structure, it was decided that, although links to specific exam boards would be mentioned where possible in lesson plans, resources would aim to offer a general coverage of these topics, and would not be tailored to specific specifications. It also became evident from researching different exam boards, speaking to teachers, and previous experience, that many exam boards provide quite prescriptive specifications and offer schemes of works including resources. Resources are therefore not intended to replace existing resources or be used exclusively without other teaching resources. They are intended to complement teachers' existing lessons.

It was also decided early in the project that not all resources would be newly designed: many good quality resources exist, especially online, and are available for free. Unfortunately teachers do not always have time to look for these resources and are not always aware of trustworthy sites. Finding and, where necessary, tailoring or differentiating these resources became an important part of the development of the resource package. Initial stages of resource development included compiling exam board specifications and searching for book and web resources.

Discussions with academics and, in particular, with practising teachers, have proved important at all stages of resource design. Resources need to be accessible for teachers, therefore a typical ‘three part lesson plan’ has been adopted for many aspects of the resource package. This involves a ‘starter’ activity to interest and engage students, the ‘main’ part of the lesson, often featuring a variety of activities, and a ‘plenary’ to review the lesson and consolidate knowledge. This is a common lesson structure in UK schools. However, it is appreciated that many teachers want additional examples and shorter activities which can be incorporated into their usual schemes of work, therefore suggested timings of activities are provided for full lessons and suggestions for variations and additional ideas are included.

Current draft resources can be found in the supplementary materials. These focus mainly on evolution and feature activities related to natural selection, geological time, evidence for evolution, and common misconceptions. It is stressed that these are under development and some activities are currently incomplete. Complying with copyright laws and gaining permissions for using images and other resources is an important consideration and resources will not be widely distributed without confirmation from all other parties.

9.1.1 Findings from informal interviews with teachers and teacher surveys

Discussions with teachers have been used in motivating activities and designing resources. During initial meetings and emails with teachers, their views on current resources and potentially useful activities were ascertained. The majority of teachers were eager to receive any resources, but many were more specific.

Popular suggestions for evolution resources are outlined in Table 9.1. These are from teacher interviews, emails, telephone calls, and from the teacher survey. The most commonly mentioned resource ideas related to evolution have been practical activities, interactive activities, and more examples of natural selection, especially if relevant to school students. A number of teachers refer to evolution as being quite a theoretical or ‘dry’ topic, and that anything to make it more applicable or amenable to students would be useful.

| Aspect | Description |
|-------------------|---|
| Evidence | Embryo development |
| | Genetic throwback |
| | Limb ratio |
| | Silent mutations |
| Fossils | Archaeopteryx |
| | Burgess Shale |
| | Gaps in fossil record |
| | Real fossils |
| Natural selection | Difference between natural selection and evolution at GCSE level |
| | Examples other than the peppered moth and Darwin's finches |
| | Marine snails/banded snails (practicals related to these?) |
| | More interesting examples |
| Theories | Lamarck vs. Darwin |
| | Primordial soup theory |
| Human evolution | Looking at the evidence and how humans evolved from primitive organisms |
| | Not descended from apes |
| Geological time | Timescale |
| General | Animations or video clips |
| | Anything which can put evolution in context and make it less of an abstract concept |
| | Common ancestry |
| | Fun practicals |
| | Evolution games |
| | Evolution that can be seen in real time |
| | Resources that focus on evidence |
| | Resources that show evolution as an on-going process |
| | Resources to challenge A* candidates |
| | Survival and competition |
| | Survival related to genes |
| | The current research |
| Other | Arguments for creationism so that both theories can be compared |
| | Evolution and Islam |
| | More ideas on how to teach the different theories of evolution e.g. intelligent design etc. |
| | Pre teaching of scepticism by religious institutions |

Table 9.1 Suggestions for evolution teaching resources and activities from secondary school teachers.

It must be emphasised that these are teachers' ideas and that not all of these are considered suitable for classroom use by the wider education community. For example, a number of teachers want resources that make comparisons between evolution and religious viewpoints including creationism and intelligent design. It is somewhat concerning in itself that science teachers would consider introducing these into a biology lesson as they may give students the impression that these 'theories' are valid alternatives to evolution. Information or training about the nature of science compared to religious explanations for life may be useful for these teachers to have, and may help them to understand why such debates are not suitable within science lessons. A number of teachers also state that they are concerned about "offending religious students" or are unsure of how to handle students who have alternative explanations. Again, ideas of how best to support teachers and avoid conflict have been considered, and insight gained from the focus groups may assist here. For example, if religious students are more comfortable about learning evolution knowing that this is acceptable within their faith, this may be a useful tactic for teachers to adopt. Ideally, greater student and teacher understanding of the different domains which science and religion occupy could provide useful, but is something that needs to be learnt about prior to evolution education.

Many other suggestions from Table 9.1 have been, or will be, incorporated into the GEVOteach resource package. These include evidence for evolution, geological time, and natural selection. Resources to be developed will focus on human evolution, practical and interactive activities, and additional examples of evolution.

Although focusing on evolution, teachers have also been asked whether there are any genetics resources or ideas they would like to develop. Generally teachers suggest that they have suitable genetics resources and ideas have been less forthcoming. As with evolution, they tend to be practical-related or interactive activities. Many involve equipment unavailable in schools and instead ask for assistance from universities. These are displayed in Table 9.2. Again, included are suggestions from teacher interviews, emails, telephone calls, and from the teacher survey. A number of these resources are being developed and will be discussed

within the ‘outreach’ section of this chapter, a number of schools have benefitted from visits to the University.

| Aspect | Description | Detail |
|-----------------------|---|---|
| Antibiotic resistance | Practicals | E.g. in university? |
| Applied genetics | Newer areas | Especially practical work |
| Cloning | Simple practical kit for use in schools | Micropropagation of plants |
| | Simulations | Interactive step-by-step process to show how and why it is done, e.g. Dolly the sheep |
| DNA | Video or animation | To show chromosomes in the nucleus then DNA structure/alleles and bases |
| Genetic engineering | How do to it | Expertise in university? |
| Inheritance | <i>Drosophila</i> lab | Simulation to show results of genetic crosses and inheritance patterns |
| | | Practical within university |
| Mitosis/meiosis | Animations, games or quizzes | Anything to help student understanding of the concepts and the differences between them |
| Mutations | Video | To show what they are and their effects plus mutagens |

Table 9.2 Suggestions for genetics teaching resources and activities from secondary school teachers.

Not all teachers felt they needed additional support in their teaching as such, but there were some interesting responses as to what assistance they would like:

“Not with teaching per se, but a re-hash of the specs [specifications] is needed so that genetics (and types of variation/reproduction) are taught just before evolution so that students understand inheritance and the mechanisms behind evolution.”

It is reassuring that teachers have similar ideas to our hypothesis regarding evolution and genetics. Another teacher asked for help in “lobbying to keep evidence for evolution in Core GCSE”. A number of teachers mentioned how much they enjoy teaching evolution.

9.2 Use of the GEVOteach resource package in schools

The initial resource package was produced for the academic year beginning September 2012. This offered relatively limited coverage of key genetics and evolution topics. Since then, further resources have been designed and improved, based on teacher and student feedback.

Most resources have only been available to schools involved in the research project. This has been to encourage more schools to be involved in the project, and also to ensure resources are of the highest standard, before they are made available to the public. A selection of resources are available online for any teachers to download through the TES (Times Educational Supplement) website. The resources have had over 4000 downloads as of January 2016 (<http://www.tes.co.uk/teaching-resource/Variation-6342585>) but no feedback has been received.

All schools involved in the project were invited to trial and evaluate resources developed as part of the project and were provided with a resource package disc. Although all schools were initially eager to have these resources, not all schools used them. Reasons for not using the resources were usually related to a lack of teacher time to look at them, rather than resources not being suitable. The resources that have been used the most are those which include different examples or information from what teachers would normally have, for example, using activities on rock pocket mice to teach natural selection. Information on the number of schools that used resources, and the activities used, can be found in the supplementary materials.

9.2.1 Feedback from teachers

Only a small amount of feedback has been received about resources. Most responses have been very positive and have typically suggested that resources are engaging and useful for teaching a variety of exam board specifications, for example: “very good and enjoyed by students”; “very engaging [...] these fit well with Edexcel spec”; “high quality resources which reflected the specification”; and “thank you for the great resources! They are really useful”. At least one

school has incorporated GEVOteach resources into their long-term school schemes of work. Although this is encouraging, very little constructive feedback has been received. Teachers have implied that a few resources, such as the *Drosophila* lab, are too complex for most students; however they do like having computer-based ideas for lessons and would appreciate similar resources that are better differentiated for lower ability students. Some teachers stated that they felt purely being involved in the research project had encouraged them to think more about what they taught and how they taught it.

9.2.1 Feedback from students

Student feedback was not something that was specifically asked for, however, written feedback was received from one school and there has also been some discussion of resources in focus groups, as discussed in Chapter 7. Generally, students appreciated having ‘different’ activities such as practicals, computer-based tasks, and videos. The geological time activities were well received and many students enjoyed guessing on a timeline. Students appreciated activities such as “how many moths” to introduce natural selection in peppered moths, and also seemed to particularly enjoy the rock pocket mice video. Some students liked the evolution “true or false” activity and particularly liked discussing human evolution through this. A number of students liked the structured worksheets, especially if they included ‘fun’ activities such as a wordsearch at the end, although others felt there was too much writing involved. Positive feedback was received on some of the PowerPoint presentations which students described as ‘interesting’, but many students wanted more practical work. Obviously, teacher involvement and possible alterations to resources will have affected the ways in which these resources were used in different classes.

Although student interest and engagement with activities is important, there are varying opinions as to how much student opinion should dictate what is taught, and how: just because an activity is popular or enjoyable, it does not mean that students have learned accurately or efficiently. Nonetheless, the feedback from students is interesting and, although from a very limited number of students, ideas will be considered when improving resources.

9.3 Quantitative findings from the resource package

Provisional findings from quantitative analyses of student pre and post are presented within this section. Although teachers were asked whether they used any of the GEVOteach resources, there are some schools for which this is unknown. Some schools did specify what resources were used, but others simply said that GEVOteach resources were used.

9.3.1 GEVOteach resources

Here, any students who used any GEVOteach resources are compared with those who didn't. Schools which did not give information about this are not included here, hence why sample sizes are lower than when previously analysed in Chapter 5. This is a very general comparison as schools varied greatly in how they used these resources and the information they gave on their use. Therefore these findings are very tentative and no strong conclusions can be drawn from them as they may reflect other factors related to teachers or classes.

Significant differences were found in evolution acceptance ($W = 211726$, $p < .001$), genetics understanding ($W = 203112.5$, $p < .001$), and evolution understanding ($W = 178708$, $p = .002$) between the two groups of students. Those who used the GEVOteach resources have higher acceptance and knowledge than those who didn't. However, as students were significantly different prior to teaching, a linked data approach was taken. Students who used any GEVOteach resources showed a greater amount of change in genetics knowledge, compared to those students who didn't ($W = 119011$, $p = .03$). Students who used GEVOteach resources also showed greater understanding of evolution ($W = 144517$, $p < .02$). No significant difference was found between post scores for evolution acceptance ($W = 143595$, $p = .22$), or between the amount of change in scores ($W = 109341.5$, $p = .77$).

These results would suggest that using the resources provided in the GEVOteach resources package have a small but significant impact on students' understanding of evolution and genetics. However, given the limited information from schools about what resources were used, it is possible that these differences may be due to

other factors, such as teachers: perhaps those teachers who take the time to use additional resources have a more positive impact on their students' education? Nonetheless, this is an encouraging finding. Full details of these analyses and associated figures can be found in the supplementary materials.

9.3.2 Rock pocket mice resources

The 'rock pocket mice' lesson was used as a bridging activity between evolution and genetics by a number of schools and received very positive feedback. It is based on activities devised by HHMI (<http://www.hhmi.org/biointeractive/making-fittest-natural-selection-and-adaptation>). This lesson includes a short video clip in which natural selection in rock pocket mice is explained in terms of mutations and alleles, and accompanying worksheets and differentiated activities based on this activity (all of which can be found in the supplementary materials). Within this section, students who used this specific resource are compared with students who did not.

Students who used the rock pocket mice activity had significantly higher evolution acceptance ($W = 154233$, $p < .001$), genetics knowledge ($W = 155861$, $p < .001$), and evolution knowledge ($W = 131455.5$, $p < .001$) than students who didn't use this resource. However, the two groups also differed before teaching. A linked data approach was again utilised. Students who used the rock pocket mice activities again had significantly higher evolution acceptance ($W = 43754.5$, $p = .049$) and showed a greater amount of increase ($W = 34753$, $p = .040$) than those students who didn't use these resources. Although very provisional findings, this is the first time that evolution acceptance has been implicated in any teaching intervention. Students who used these resources also had significantly increased evolution understanding ($W = 40095.5$, $p = .01$). There was no significant difference in genetics understanding between students who used this resource and those who didn't ($W = 42242$, $p = .07$). Again, full details and figures can be found in the supplementary materials.

Although there are a number of interesting, significant results here, too little is known about the ways in which the different resources were used to make firm conclusions. Limited student numbers mean that comparisons between topic order

or ability have not been possible. One hypothesis behind why students who use additional resources show some increased acceptance and knowledge compared to those who don't is that the effects are more to do with their teachers: are teachers who are willing to use new resources and try different activities actually putting more time into planning and preparation of these topics, and are these classes actually spending longer on these topics? These would certainly be interesting questions to attempt to answer; however, further information or more controlled conditions are needed to make direct comparisons. This is beyond the scope of this research project but would make for an intriguing, albeit challenging, future research area. It is encouraging to think that the GEVOteach resources are having a significant, positive impact on students, but other factors, especially teacher effects, must be taken into consideration.

9.4 School outreach

Many schools are eager to utilise university facilities and make links with scientific experts. They are also keen to provide their students with exposure to Higher Education, with some schools worried that their students typically go to the same, local universities and colleges, and are not aware of other options.

The potential to visit the University of Bath and complete practical work in the teaching laboratories provided another means of initially encouraging school involvement in this project. Given responses from teachers about useful genetics resources (including those in Table 9.2), this has also allowed teachers to fulfil aspects of their curricula that they may otherwise have struggled with, given limited equipment and expertise in schools.

To date, involvement in GEVOteach has enabled three schools to visit the University, with many others showing interest. The primary reason for these visits has been to participate in practical lab work, usually related to DNA and genetics. These visits have also enabled students to experience lectures and tours of campus. Positive feedback has been received from teachers and students. Although no data have been recorded as to the effectiveness of these outreach activities, anecdotally these activities have proved very successful and there is

certainly scope for expanding activities available for schools within universities, and there is the potential for research associated with this.

A number of schools have wanted to participate in outreach to the University but have been unable to. The potential to offer outreach within schools, such as mobile labs and speakers in schools, has been considered and are another area of potential development. It is certainly recommended that schools consider approaching local universities and science centres when planning different teaching activities, particularly where specialist equipment or expertise could benefit students' learning. Discussions with teachers suggest that these often appear overlooked, or, where teachers have considered universities, they do not know who to approach or how to go about arranging visits. This seems a shame given the potential benefits to both schools and universities, especially given the increased recognition of the importance of outreach within universities.

9.5 Summary and implications for teaching

Resources developed through the GEVOteach project appear to be beneficial for students who use them. Even though initial quantitative findings should be interpreted with caution, they suggest that these resources do have a positive effect on students' understanding of evolution and genetics. Of particular interest is the suggestion that activities which link natural selection to mutations, in this case using rock pocket mice, increase student understanding and acceptance of evolution. There are many other factors which need to be taken into consideration, but this is very encouraging and suggests that links between genetics and evolution may help students to better understand and accept evolution.

There is still much work to be completed on resources based on recent feedback and findings from this study. Once complete, these resources will be widely available through websites including the TES. Resources will also be distributed to teachers involved in the project through GEVOteach memory sticks. There has been some interest from UK exam boards and teaching bodies to provide links to these resources. Given the potential for resources to improve student understanding, and possibly acceptance of, evolution, wider use of such resources

should be encouraged. However, teachers' professional judgements as to what is suitable for their classes are also an important consideration.

Chapter 10. Discussion

Many important findings have been reported throughout this investigation. Within this chapter I first summarise key findings in relation to the original research questions and objectives. I then discuss what these findings mean and how they may interact with each other, utilising research from student questionnaires and focus groups, and from teacher surveys. This is followed by a critique of the study and limitations that should be considered when interpreting the data. The contribution of this work to science education knowledge is summarised and implications for teaching are considered.

10.1 Summary of key findings

With respect to the four key research questions asked in Chapter 1, we report the following findings:

1. Students' knowledge of genetics is positively correlated to their understanding and acceptance of evolution, even before learning about these topics.
2. Teaching has a positive and lasting effect on acceptance of evolution, knowledge of genetics, and knowledge of evolution.
3. Academic ability affects acceptance of evolution and understanding of evolution and genetics: higher ability students have higher acceptance and greater knowledge than lower ability students.
4. Topic order affects understanding of evolution: teaching genetics before evolution has a positive impact on knowledge of both evolution and genetics.

In addition, we find that student acceptance of evolution is high, with few students showing rejection. Students have reasonable knowledge of many aspects of genetics but poor understanding of evolution. Many misconceptions are predominant, particularly relating to the inheritance of acquired characteristics and human evolution.

Teachers and pre-service teachers are very highly accepting of evolution. Knowledge of genetics is good, but pre-service teachers show weaker evolution understanding. Relationships between teachers' acceptance and knowledge of genetics and evolution follow a similar trend to that seen in students. Surprisingly, no relationship is found between pre-service teacher's acceptance of evolution and knowledge of genetics. Teaching resources have been developed and distributed to schools. Feedback has been positive and provisional findings imply activities which link genetics with evolution have a positive impact on students' understanding and acceptance of evolution.

These findings raise many intriguing points. The place of knowledge about genetics in understanding and accepting the theory of evolution is intrinsic to this research. Even before students learn about evolution, positive correlations between genetics and evolution are found. These often appear strongest between evolution acceptance and genetics knowledge, suggesting that understanding of genetics may be a better predictor of acceptance, than evolution knowledge is. However, these relationships are relatively weak to moderate and are not necessarily causative.

Learning about genetics before evolution appears to improve evolution and genetics understanding. The reasons as to why this topic order may improve evolution knowledge are evident, but the reasons behind the increase in genetics knowledge are less clear. It is possible that better understanding of evolution actually improves understanding of genetics? If understanding has improved, why is no change observed in evolution acceptance?

Comparing results from topic order with those examining the effectiveness of resources which combine genetics and evolution would suggest that knowledge of genetics does effect evolution understanding. Yet the results differ for genetics knowledge and evolution acceptance. This begs the question, what is different about these two interventions? Changes to the topic order simply involve teaching one way or the other and do not infer any links between the two are being made by teachers or by students. The teaching activities which incorporate genetics into

evolution do make clear links between the two. Could it be that it is only when links are made that students become more accepting?

Then there is the curiosity of the relatively poor relationship between acceptance and understanding. Teaching evolution works. Teaching genetics works. But there appears to be a dislocation between understanding and acceptance at a variety of levels: school students and teachers show weak to moderate correlation, but most unexpectedly, pre-service teachers show no correlation between genetics understanding and evolution acceptance.

This also raises the question of what is knowledge? Although the terms knowledge and understanding have been used synonymously, there is a difference between the two. While students might have knowledge of a topic, they may not really understand it. Perhaps a better distinction between these terms would provide more insight into relationships with acceptance. Discussions with students would suggest that they *know* evidence for evolution exists, yet few are able to describe any of this evidence in any detail or even give examples. They appear to have limited *understanding* of evidence. However, these students are still accepting of evolution. This also leads to the question, *what* is known? Are there particular areas of genetics or evolution knowledge that provoke evolution acceptance? Or indeed, are there specific aspects of genetics knowledge that enrich evolution knowledge?

Is knowledge of genetics causative of a higher level of evolution acceptance or could this be indicative of higher intelligence or academic ability? Higher ability students show higher acceptance of evolution. They also demonstrate greater knowledge of evolution and genetics. This might imply that knowledge does effect acceptance; however, correlations between the two do not seem so evident. Why then do higher ability students have higher acceptance than lower ability students? Could this be linked to another facet that higher ability students tend to have compared to lower ability students, such as logical reasoning skills? Are higher ability students any more or less likely to have alternative beliefs, compared to lower ability students?

There are clearly many other factors that could influence evolution acceptance. Focus groups suggest that authority figures are important, as is religion for some students. It should also be remembered that, although teaching has a positive impact on most students, there are some students who demonstrate no or even negative changes in acceptance and knowledge. The reasons behind this are not clear. Some stochastic fluctuation is to be expected and the ‘ceiling effect’ of the questionnaire may be observed among those that demonstrate high acceptance or knowledge prior to teaching. But does this explain all of the changes observed? If not, what explanations are there for these differences? Some students spoke in the focus groups of expecting there to be more evidence for evolution than was presented in their lessons. Is it possible that this could affect acceptance?

The findings from this research ignite many further questions. These ideas proposed here are purely hypothetical and beyond the scope of this project, but many shall be discussed further within the future work section of this chapter.

10.2 Limitations

There are a number of caveats which must be considered, particularly in relation to the student questionnaire. First I discuss the limitations related to the research instruments used. I then consider sample sizes and potential bias that may arise from self-selection. Other potentially influential factors were not controlled for within this investigation. I suggest what these variables are and what their potential impacts might be.

10.2.1 Limitations of the research instruments

As with all studies of this nature, there are various limitations to the use of questionnaires. Although analysis of the student and teacher questionnaires found them to be reliable and valid for their purpose, flaws did become apparent.

Time constraints meant only a small range of concepts could be covered in the student questionnaire. The number of questions within each of the three sections varied considerably, as did the weighting of marks given for different sections and questions. The teacher survey was longer and allowed better detection of small

changes in acceptance and understanding of evolution. Some of the genetics questions may have been too simplistic. The evolution questions on the student questionnaire appeared very difficult and this, combined with the low number of questions, meant discriminating between students was difficult, and any changes detected tended to be very small.

All knowledge and acceptance questions were variations of the multiple choice question and thus may have 'forced' participants into choosing answers they did not wholly agree with. Providing questions which allowed for participants to write freely could, arguably, have provided insightful information. Some of the questions did not necessarily have one 'correct' answer. Although unlikely to be recognised as such by students of this academic ability, this may have been more problematic with teachers (although this did not appear to be the case).

When inputting data for the student questionnaire there was the potential for error. Although this has been calculated and is not thought to be important, a more automated way, as was utilised in the teacher survey, may have proved more efficient. Decisions regarding instances of item non-response may have inadvertently affected individuals' totals for evolution and acceptance. Again, although analysis was undertaken into this, the reasons behind participants not responding are unknown and could conceal important information.

Focus groups also have their limitations. Many of these are general constraints of this research method. For example, later speakers are likely to be influenced by earlier speakers. There were quite a few instances of students repeating what previous speakers had said, or saying they agreed or would have said what a previous participant said. However this is the nature of focus groups and it did lead to some interesting discussion, particularly if students did not agree, or in discussing misconceptions. Students might not remember correctly, or may be influenced by their peers. Although entirely necessary, the presence of adults such as teachers may also have influenced students' responses.

Although the focus groups provided lots of interesting information, much of this was related to opinion. A different structure may have been useful, particularly

when considering students' knowledge. For example, students could have been given a task or a problem solve. This may have probed more specific understanding.

10.2.2 Sample size and selection

This is the largest research project of its kind in the UK; however, there was a relatively low uptake of participation from schools, especially given the number that were contacted. Schools are somewhat self-selecting. Many appeared to be quite high achieving and/or had teachers who were particularly interested in evolution. No academies were involved in the project and very few faith schools participated.

Although a very large student cohort completed the questionnaire at least once, student absences did mean the number of paired comparisons was considerably lower. Although teachers selected classes so that the students themselves were not self-selecting, the questionnaires tended to be completed by higher ability classes. This meant that further analyses of lower ability students were not always possible. Similarly, although this was a random control trial, a greater proportion of classes were taught genetics first. Again, this made further analyses more difficult, especially where comparing ability and topic order.

The teacher and pre-service teacher surveys are self-selecting. It is possible that teachers who participated were particularly interested in evolution or that the sample was biased in other ways. The sample size, particularly for pre-service teachers, was quite small. The focus groups were also relatively self-selecting, although teachers did influence this. All students were categorised as 'higher ability' within the context of the project and as such, any hesitant generalisations should be confined to this category of students.

10.2.3 Other influential factors

There were many other potential variables that were not controlled for within this research. It is important to acknowledge that these factors might have had an impact on students' learning of evolution and genetics. School effects include the school type, hours spent on science and on these topics, the length of lessons, and

examination board used. There are also teacher effects which may include prior experience, personal views, and teaching methods and resources used. Students themselves are likely to differ greatly in terms of background demographics.

Student ability was categorised based on class information. These categorisations are very crude and do not allow for variation within classes. There are issues related to this division of higher and lower abilities: setting might not be the same across different schools, for example, some schools may be set based on English and maths results and not science grades, whereas other schools may set classes based purely on students' results within that subject. There is no clear definition of what students have ability in. Even if a student is in a 'higher' class, they may not be entered for a higher tier exam (this differs between schools). One school did not set its classes due to small student numbers. Although all students within this school were classified as 'higher', but given some additional information from the school, this is unlikely to be accurate for all students.

Other considerations related to the categories might effect students' learning. For example, those students studying for triple or separate science will by the very nature of the qualification study more science (in terms of number of hours per week, and more subject content) than those studying for the double award. Those students studying at higher tier will study more science content than those studying lower tier. Therefore, there may be some differences in knowledge which are due to teaching (content taught and hours spent on the subject) rather than *intelligence* or ability of the students.

Despite these limitations, findings from this investigation would appear valid and reliable. There are improvements that could have been made, particularly to the student questionnaire. However, given the nature of this in-school research and the associated teaching time constraints, it seems compromises need to be made. Here, this was between the length of the questionnaire and the level of student participation.

10.3 Future work

This investigation has probed many intriguing questions, as found earlier in this chapter. Of these, the importance of topic order and other associated variables are the most important. Further research is needed into whether links between genetics and evolution are made regardless of topic order and, if so, whether these are made by teachers or by students themselves. Also, why does genetics knowledge also increase among students taught genetics first? The potential impact of resources, especially those which link genetics with evolution, needs more research.

There is much still to be discovered about the differences between knowledge and understanding, and their relationship with acceptance. Most likely there are many factors interacting. More data related to other potentially influential factors could be important and multivariable analysis may reveal further insight. Any continuation of this work should also consider ways of increasing sample size and diversity including more schools from a wider geographical area.

The student questionnaire used within this research proved appropriate for school students to use, but did have its limitations as discussed above. Improving this valuable research instrument could provide further insight into secondary school students' acceptance and knowledge: a replacement for the item that was deleted following initial analysis should be found; knowledge questions could be developed further to include more aspects of the topics; less emphasis could be placed on easier genetics questions; and the evolution section in particular would benefit from additional questions. Possibly a larger selection of questions could be piloted with more students to discover the most informative or discriminating questions.

Work related to teacher surveys and resource development is on-going. Data collected from teachers and pre-service teachers will be analysed further. Key questions include: why is there no correlation between pre-service teachers' acceptance of evolution and knowledge of genetics? Why do teachers have significantly greater evolution knowledge than pre-service teachers? And is

teacher knowledge related to teaching experience? These will also be compared with data from primary school teachers and non-science secondary school teachers. Further ways to support teachers when teaching evolution will be investigated and the resources package will be finalised and distributed to teachers.

10.4 Contribution of knowledge to science education

This is the first study to specifically investigate the relationship between evolution and genetics among secondary school students. Its findings are clear: there are positive relationships between understanding genetics and understanding and accepting evolution. Most importantly, topic order is implicated in increasing understanding of these topics: students who are taught genetics before evolution have significantly greater knowledge of evolution and genetics, compared to students who are taught evolution first. More tentatively, it is suggested that teaching resources which link genetics and evolution have a positive effect on evolution understanding and acceptance. This investigation also provides evidence that teaching has a positive impact on acceptance and knowledge, and that evolution acceptance is linked to ability.

There are few studies involving secondary school students with which our data can be compared. However, qualitative data from this study provide credence to previous studies which have found evolution acceptance may be linked to authority figures (e.g. Donnelly *et al.* 2009), and suggests similar results regarding evolution compatibility to religious beliefs as Yasri and Mancy (2014). Interestingly, our research disagrees with that of Rutledge and Warden (2000) and Donnelly *et al.* (2009) which finds human evolution the least accepted aspect of evolution.

Overall, evolution acceptance is high among secondary school students and very high among teachers. Student acceptance is in keeping with findings from Miller *et al.*'s 2006 study, but teacher acceptance is far greater than that of the public. Knowledge of students surveyed in questionnaires and focus groups is clearly higher than that discovered in the British Council's 2009 survey of public

attitudes towards evolution and Charles Darwin. These findings regarding evolution acceptance are encouraging.

10.5 Practical applications for teaching

Although there are many aspects of this research that would benefit from further investigation and the relationships between evolution and genetics and knowledge and acceptance are not fully understood, many of our findings do have practical applications within science classes. Initial findings about teaching resources which link evolution and genetics are exciting: it is hoped that future work might provide insight into how and why these links may improve evolution understanding and acceptance. Evidence surrounding student misconceptions are clear and suggest areas for improvement. Qualitative findings from student focus groups and teacher discussions suggest the importance of engaging students through relevant examples and practical activities, and also the importance for some students of understanding that evolution does not have to conflict with their personal beliefs. The influence of authority figures is emphasised. However, of these findings, one is prominent in terms of its simplicity and ease of use. This project provides a simple intervention to improve understanding of evolution that will not involve additional input from teachers or costs to schools: teach genetics before evolution.

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Appendix A

Student questionnaire

Section A. Please circle 'strongly agree', 'agree', 'undecided', 'disagree', or 'strongly disagree' to indicate your opinion of each of the following statements.

1. Plants and animals that are alive today are the result of evolutionary processes that have occurred over millions of years.

Strongly Agree Agree Undecided Disagree Strongly Disagree
2. The theory of evolution is based on guesswork and not valid scientific observation and evidence.

Strongly Agree Agree Undecided Disagree Strongly Disagree
3. Modern humans are the product of evolutionary processes that have occurred over millions of years.

Strongly Agree Agree Undecided Disagree Strongly Disagree
4. There are large amounts of factual, historical, and laboratory data that support evolutionary theory.

Strongly Agree Agree Undecided Disagree Strongly Disagree
5. Most scientists accept evolutionary theory to be correct.

Strongly Agree Agree Undecided Disagree Strongly Disagree
6. It is not possible to scientifically disprove the theory of evolution.

Strongly Agree Agree Undecided Disagree Strongly Disagree
7. The first humans lived at the same time as dinosaurs.

Strongly Agree Agree Undecided Disagree Strongly Disagree
8. The theory of evolution cannot be correct since it disagrees with religious accounts of creation.

Strongly Agree Agree Undecided Disagree Strongly Disagree
9. The age of the earth is less than 20,000 years.

Strongly Agree Agree Undecided Disagree Strongly Disagree
10. Evolutionary theory generates testable predictions with respect to the characteristics of life.

Strongly Agree Agree Undecided Disagree Strongly Disagree
11. Much of the scientific community doubts if evolution occurs.

Strongly Agree Agree Undecided Disagree Strongly Disagree
12. Humans exist today in the same form in which they always have.

Strongly Agree Agree Undecided Disagree Strongly Disagree

13. Dinosaurs and humans have never existed at the same time.

Strongly Agree

Agree

Undecided

Disagree

Strongly Disagree

14. The age of the earth is approximately 4-5 billion years.

Strongly Agree

Agree

Undecided

Disagree

Strongly Disagree

Section B.

15. Place the following items in order of size, starting with the largest first:

cell, chromosome, gene, organism, nucleus

Largest:

|

|

|

|

Smallest:

16. Complete the following table by placing a tick (to give the answer 'yes'), cross (to give the answer 'no') or question mark (to give the answer 'unsure') in each box.

| | Are they living organisms? | Are they animals? | Are they made up of cells? | Do they contain genetic information? |
|----------|-----------------------------------|--------------------------|-----------------------------------|---|
| Humans | | | | |
| Giraffes | | | | |
| Moths | | | | |
| Oak Tree | | | | |
| Bacteria | | | | |
| Virus | | | | |

17. Complete the following table by using the words in the box below. Each word may be used once, more than once, or not at all. Only one word is needed for each definition.

| | | | |
|----------------------|------------------|-------------------|-----------------|
| <i>environmental</i> | <i>genetic</i> | <i>chromosome</i> | <i>sexual</i> |
| <i>DNA</i> | <i>alleles</i> | <i>asexual</i> | |
| <i>clone</i> | <i>variation</i> | <i>gamete</i> | <i>nucleus</i> |
| | | | <i>mutation</i> |

| Word | Definition |
|------|--|
| | Different forms of genes |
| | A change to the DNA sequence |
| | An individual that is genetically identical to its parents |
| | A sex cell |
| | Reproduction which needs only one parent |
| | Variation which is due to inheritance |

Please circle the correct answer for the following questions. Each question only has **one** correct answer

18. Muscle cells, nerve cells, and skin cells have different functions because each type of cell

- A. Contains different kinds of genes.
- B. Is located in different areas of the body.
- C. Activates different genes.
- D. Contains different numbers of chromosomes.

19. How do plants reproduce?

- A. Sexual reproduction.
- B. Asexual reproduction.
- C. Both sexual and asexual reproduction.
- D. Plants do not reproduce.

20. Transferring genes from one organism to another is called

- A. Cloning.
- B. Evolution.
- C. Genetic engineering.
- D. Tissue culture.

Section C. Please circle the correct answer for each question. Each question only has **one** correct answer.

21. Which of the following phrases best describes evolution?
- A. The development of man from monkey-like ancestors.
 - B. The change of simple to complex organisms.
 - C. The development of characteristics in response to need.
 - D. Genetic changes in populations through time.
22. Which of the following is not a part of the theory of evolution by natural selection?
- A. Individuals of the same species show variation.
 - B. Organisms tend to produce more offspring than survive to adulthood.
 - C. Modifications an organism acquires during its lifetime can be passed to its offspring.
 - D. Some characteristics can be inherited.
23. Which of the following statements is most acceptable from an evolutionary point of view?
- A. Apes and humans have evolved from a common ancestor.
 - B. Humans have evolved from apes.
 - C. Certain apes have gradually evolved into humans.
 - D. Apes and humans are related.
24. Scientists surveyed the number of light and dark coloured moths in woods where trees had either light or dark (polluted) coloured trunks. They found more light coloured moths in woods with light trees and more dark coloured moths in woods with polluted trees. This data provides support for
- A. Artificial selection.
 - B. Extinction.
 - C. Inheritance of acquired characteristics.
 - D. Natural selection.
25. Natural selection is
- A. The same thing as evolution.
 - B. A possible but unproven mechanism of evolution.
 - C. Only one of many possible mechanisms of evolution.
 - D. The inheritance of acquired characteristics.
26. Scientists have found evidence to suggest that the first life appeared on earth approximately:
- A. 10 thousand years ago.
 - B. 270 million years ago.
 - C. 3 billion years ago.
 - D. 6 billion years ago.

Appendix B

Student focus group structure

Focus Group Questions

School:

Date and time:

1. Opening (introductions)

- Can you tell me who are you? (name badges) and something very simple about yourself, for example, what subjects do you like in school? – I'll go first...
 - Participant 1
 - Participant 2
 - Participant 3
 - Participant 4
 - Participant 5
 - Participant 6

2. Introductory

- What is the **first thing** that comes to mind when you hear the word **evolution**?

3. Transition

- Do you remember **learning** about the theory of evolution in school during your biology or science class?
 - Do you remember any lessons or activities in particular?
 - Did you enjoy learning about evolution?
 - Was this the **first time** you had heard of evolution?
 - **Where else** have you learnt about evolution?
- How would you **define** (biological) evolution?

4. Key

- What are **your views** on evolution?
- Do you agree that **plants and animals** that are alive today are the result of evolutionary processes that have occurred over millions of years?
- Does this include **modern humans**: do you think that we are the product of evolutionary processes that have occurred over millions of years? Or do you think that humans exist today in the same form in which they always have?
- Do you think there is much **evidence** that supports evolutionary theory?
- What (other) **evidence** can you think of for evolution?
- What do you think is the **best or most convincing evidence** for evolution?
- Do you think evolution is linked with **genetics**? Are there any links between evolution and genetics?
- How or why?

5. Ending (brief summary of main points)

- Have we missed anything?
- Is there anything else we should have talked about but didn't?

Thank you very much for your time 😊

Appendix C

Teacher survey

Pre service teacher survey

Evolution Survey for Teachers

Overview

This survey is part of the GEVOteach Project which is investigating how best to teach evolution in primary and secondary schools. By completing this survey you will be helping research by the Evolution Education Trust and the University of Bath.

The survey should take 15-20 minutes to complete. Please answer all questions and complete this survey without the help of any resources. Your views are important, not getting the 'right' answers!

All responses will be kept strictly confidential.

By completing this survey you will have the chance to sign up to receive a free GEVOteach memory stick containing full teaching resources for evolution topics. You will also have the chance to win a £50 Amazon voucher.

If you (or anyone else) has any questions about this project, then please do contact us:

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twitter: <http://twitter.com/GEVOteach>

~ Thank you ~

Evolution Survey for Teachers

Background Information

* 1. In what county do you current work?

* 2. In what type of school do you work?

- ☐ Primary
- ☐ Junior
- ☐ Middle
- ☐ Secondary
- ☐ Further Education
- ☐ Other (please specify)

* 3. In which sector do you work?

- ☐ Independent
- ☐ State funded
- ☐ Other (please specify)

* 4. Do you remember learning about evolution at any of these stages? (Please select all that apply.)

- ☐ GCSE or equivalent
- ☐ A Level or equivalent
- ☐ Degree
- ☐ Do not remember learning about evolution
- ☐ Other (please specify)

* 5. For how many years have you been teaching?

* 6. What is your highest qualification in biology?

- ☐ GCSE or equivalent
- ☐ A Level or equivalent
- ☐ Degree
- ☐ Other (please specify)

* 7. Do you identify with any of the following religions?

- ☐ Christianity
- ☐ Judaism
- ☐ Islam
- ☐ Buddhism
- ☐ Hinduism
- ☐ No religion
- ☐ Prefer not to say
- ☐ Other (please specify)

* 8. What is your gender?

- ☐ Female
- ☐ Male
- ☐ Other
- ☐ Prefer not to say

Evolution Survey for Teachers

Evolution Acceptance (adapted from Rutledge and Warden 1999)

* 9. Please indicate your opinion for each of the following statements.

| | Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
|---|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 1. Organisms existing today are the result of evolutionary processes that have occurred over millions of years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 2. The theory of evolution is incapable of being scientifically tested. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 3. Modern humans are the product of evolutionary processes that have occurred over millions of years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 4. The theory of evolution is based on speculation and not valid scientific observation and testing. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 5. Most scientists accept evolutionary theory to be a scientifically valid theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 6. The available data are ambiguous as to whether evolution actually occurs. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 7. The first humans lived at the same time as dinosaurs. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 8. The age of the earth is less than 20,000 years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 9. There is a significant body of data that supports evolutionary theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

| | Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 10. Organisms exist today in essentially the same form in which they always have. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 11. Evolution is not a scientifically valid theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 12. The age of the earth is at least 4 billion years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 13. Current evolutionary theory is the result of sound scientific research and methodology. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 14. Evolutionary theory generates testable predictions with respect to the characteristics of life. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 15. The theory of evolution cannot be correct since it disagrees with religious accounts of creation. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 16. Humans exist today in essentially the same form in which they always have. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 17. Evolutionary theory is supported by factual historical and laboratory data. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 18. Much of the scientific community doubts if evolution occurs. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 19. The theory of evolution brings meaning to the diverse characteristics and behaviours observed in living forms. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 20. With few exceptions, organisms on earth came into existence at about the same time. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 21. Evolution is a scientifically valid theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

22. Dinosaurs and humans have never existed at the same time.

Strongly Agree

☐

Agree

☐

Undecided

☐

Disagree

☐

Strongly Disagree

☐

Evolution Survey for Teachers

Evolution Knowledge - Canary Island Lizards (adapted from Anderson, Fisher and Norman 2002)

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc.

Three different species of lizards found on the islands are similar to one species found on the African continent (Thorpe & Brown, 1999).

Because of this scientists assume that the lizards travelled from Africa to the islands by floating on tree trunks washed out to sea.

* 10. Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?

- ☐ Finding food is not a problem since food is always in abundant supply.
- ☐ Since lizards eat a variety of foods, there is likely to be enough food for all the lizards at all times.
- ☐ Lizards can get by on very little food, so the food supply does not matter.
- ☐ It is likely that sometimes there is enough food, but at other times there is not enough food for all the lizards.

* 11. What do you think happens among lizards of a certain species when the food supply is limited?

- ☐ The lizards compete for food and share what they find.
- ☐ The lizards fight for the available food and the stronger lizards kill the weaker ones.
- ☐ Genetic changes that would allow the lizards to eat new food sources are likely to be induced.
- ☐ The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

* 12. Populations of lizards are made up of hundreds of individual lizards. Which statement describes how similar they are likely to be to each other?

- ☐ All lizards in the population are likely to be nearly identical.
- ☐ All lizards in the population are identical to each other on the outside, but there are differences in the internal organs such as how they digest food.
- ☐ All lizards in the population share similarities, but there are differences in features like body size and claw length.
- ☐ All lizards in the population are completely unique and share no features with other lizards.

* 13. Which statement could describe how traits in lizards pass from one generation of lizards to the next generation?

- ☐ Lizards that learn to catch a particular type of insect will pass the new ability to their offspring.
- ☐ Lizards that are able to hear, but have no survival advantage because of hearing, will eventually stop passing on the "hearing" trait.
- ☐ Lizards with stronger claws that allow them to catch certain insects have offspring whose claws gradually get even stronger during their lifetime.
- ☐ Lizards with a particular colouration and pattern are likely to pass the same trait on to their offspring.

* 14. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional female lizards. Which lizard might a biologist consider to be the "most fit"?

| | Body length (cm) | Number of offspring surviving to adulthood | Age at death (years) | Comments |
|--------------------|------------------|---|-------------------------|--------------------------|
| Lizard A clever | 20 | 19 | 4 | Very healthy, strong and |
| Lizard B | 12 | 28 | 5 | Mated with many lizards |
| Lizard C quick | 10 | 22 | 4 | Dark coloured and very |
| Lizard D | 15 | 26 | 6 | Has largest territory |

- ☐ Lizard A
- ☐ Lizard B
- ☐ Lizard C
- ☐ Lizard D

* 15. According to the theory of natural selection, where did the variation in body size in the three species of lizards most likely come from?

- ☐ The lizards needed to change in order to survive, so beneficial new traits developed.
- ☐ The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
- ☐ Random genetic and sexual recombination both created new variations.
- ☐ The island environment caused the genetic changes in the lizards.

* 16. What would cause one species to change into three species over time?

- ☐ Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
- ☐ Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.
- ☐ There may be minor variations, but all lizards are essentially alike and all are members of a single species.
- ☐ In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

Evolution Survey for Teachers

Evolution Knowledge - General Questions

* 17. Which of the following phrases best describes the process of evolution?

- ☐ The development of man from monkey-like ancestors.
- ☐ The change of simple to complex organisms.
- ☐ The development of characteristics in response to need.
- ☐ Genetic change in populations through time.

* 18. Which of the following is not a part of the theory of evolution by natural selection?

- ☐ Individuals of the same species show variation.
- ☐ Organisms tend to produce more offspring than survive to adulthood.
- ☐ Modifications an organism acquires during its lifetime can be passed to its offspring.
- ☐ Some characteristics can be inherited.

* 19. Which of the following statements is most acceptable from an evolutionary point of view?

- ☐ Apes and humans have evolved from a common ancestor.
- ☐ Humans have evolved from apes.
- ☐ Certain apes have gradually evolved into humans.
- ☐ Apes and humans are related.

* 20. Scientists surveyed the number of light and dark coloured moths in woods where trees had either light or dark (polluted) coloured trunks. They found more light coloured moths in woods with light trees and more dark coloured moths in woods with polluted trees. This data provides support for:

- ☐ Artificial selection.
- ☐ Extinction.
- ☐ Inheritance of acquired characteristics.
- ☐ Natural selection.

* 21. Natural selection is:

- ☐ The same thing as evolution.
- ☐ A possible but unproven mechanism of evolution.
- ☐ Only one of many possible mechanisms of evolution.
- ☐ The inheritance of acquired characteristics.

* 22. Scientists have found evidence to suggest that the first life appeared on earth approximately:

- ☐ 10 thousand years ago.
- ☐ 270 million years ago.
- ☐ 3 billion years ago.
- ☐ 6 billion years ago.

* 23. The wing of the bat and the fore-limb of the dog are said to be homologous structures. This indicates that:

- ☐ They have the same function.
- ☐ Bats evolved from a lineage of dogs.
- ☐ They are structures which are similar due to common ancestry.
- ☐ The limb bones of each are anatomically identical.
- ☐ They have a different ancestry but a common function.

* 24. Marine mammals have many structural characteristics in common with fishes. The explanation that evolutionary theory would give for this similarity is:

- ☐ Fish and mammals are closely related.
- ☐ Fish evolved structures similar to those already existing in mammals.
- ☐ Marine mammals evolved directly from the fishes.
- ☐ Marine mammals never developed use of limbs.
- ☐ Marine mammals adapted to an environment similar to that of the fishes.

* 25. Please confirm which school age you mainly teach:

- ☐ Primary
- ☐ Secondary

Evolution Survey for Teachers

Genetics Knowledge

* 26. Place the following items in order of size, starting with the largest first (1) and the smallest last (5):

| | | |
|----------------------|--------------------------|------------|
| <input type="text"/> | <input type="checkbox"/> | Cell |
| <input type="text"/> | <input type="checkbox"/> | Chromosome |
| <input type="text"/> | <input type="checkbox"/> | Gene |
| <input type="text"/> | <input type="checkbox"/> | Organism |
| <input type="text"/> | <input type="checkbox"/> | Nucleus |

* 27. Complete the following table by placing a tick in each of the boxes where you consider "yes" to be the answer to the question:

| | Are they living organisms? | Are they animals? | Are they made up of cells? | Do they contain genetic information? |
|----------|-------------------------------|--------------------------|-------------------------------|---|
| Humans | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Giraffes | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Moths | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Oak Tree | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Bacteria | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Virus | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

* 28. Complete the following table by choosing the words which best fits the description. Each word may be used once, more than once, or not at all.

| | environmental | genetic | sexual | DNA | alleles | asexual | clone | variation | gamete | mutation |
|---|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Different forms of genes. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| A change to the DNA sequence. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| An individual that is genetically identical to its parents. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| A sex cell. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Reproduction which needs only one parent. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Variation which is due to inheritance. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

* 29. Muscle cells, nerve cells, and skin cells have different functions because each type of cell:

- ☐ Contains different kinds of genes.
- ☐ Is located in different areas of the body.
- ☐ Activates different genes.
- ☐ Contains different numbers of chromosomes.

* 30. How do plants reproduce?

- ☐ Sexual reproduction.
- ☐ Asexual reproduction.
- ☐ Both sexual and asexual reproduction.
- ☐ Plants do not reproduce.

* 31. Transferring genes from one organism to another is called:

- ☐ Cloning.
- ☐ Evolution.
- ☐ Genetic engineering.
- ☐ Tissue culture.

Evolution Survey for Teachers

Confidence and Comments

* 32. For the following items, please indicate your level of confidence with the given statements:

Not at all confident Not confident Fairly confident Confident Really confident

How confident are you about teaching students how to "Recognise that living things have changed over time and that fossils provide information about living things that inhabited the Earth millions of years ago."?

☐☐☐☐☐

How confident are you about teaching students how to "Recognise that living things produce offspring of the same kind, but normally offspring vary and are not identical to their parents."?

☐☐☐☐☐

How confident are you about teaching students how to "Identify how animals and plants are adapted to suit their environment in different ways and that adaptation may lead to evolution."?

☐☐☐☐☐

Evolution Survey for Teachers

Confidence and Comments

* 33. For the following items, please indicate your level of confidence with the given statements:

| | Not at all confident | Not confident | Fairly confident | Confident | Really confident |
|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| How confident are you about teaching science in general? | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| How confident are you about teaching evolution? | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

* 34. Do you have any major concerns about teaching evolution?

* 35. Do you think there are any areas of evolution that you need further support with?

* 36. How could the GEVOteach Project help to support you? (Please select all that apply.)

- ☐ Discussion with other teachers
- ☐ Inset training
- ☐ Resources
- ☐ Web based information
- ☐ I don't feel as though I need any support
- ☐ Other (please specify)

* 37. Do you have any other comments you would like to make about teaching evolution?

Evolution Survey for Teachers

Contact Details for Free Resources

38. Please provide us with your contact details if you would like to receive free resources from GEVOteach*.

| | |
|-----------------------|----------------------|
| Name | <input type="text"/> |
| School Name | <input type="text"/> |
| School Address | <input type="text"/> |
| Address 2 | <input type="text"/> |
| City/Town | <input type="text"/> |
| County | <input type="text"/> |
| Postal Code | <input type="text"/> |
| Country | <input type="text"/> |
| Email Address | <input type="text"/> |
| Phone Number | <input type="text"/> |

* Memory sticks will be posted to the first 50 primary and the first 50 secondary school teachers to complete this survey before 30/09/15. Resources will be sent via disc or internet link to all other teachers who complete the survey and indicate that they would like to receive resources. Resources will be available from October 2015 onwards.

39. Please provide us with your contact details if you would like to be entered into a draw to win an Amazon voucher worth £50**.

| | |
|----------------------|----------------------|
| Name | <input type="text"/> |
| Email Address | <input type="text"/> |
| Phone Number | <input type="text"/> |

** Survey must be completed on or before 30/09/15 to be entered into the draw.

40. Please provide us with your contact details if you would like to receive more information about GEVOteach research.

Name

School Name

Email Address

Phone Number

Please complete this survey by clicking on the **Done** button (below).

All responses will be kept strictly confidential.

If you (or anyone else) has any questions about this project, then please do contact us:

Dana Buchan (Primary Schools) Rebecca Mead (Secondary Schools)
Department of Biology and Biochemistry
University of Bath
BA2 7AY

email: l.buchan@bath.ac.uk (Primary) r.mead@bath.ac.uk (Secondary)

tel: 01225 385902

website: <http://go.bath.ac.uk/GEVOteach>

twitter: <http://twitter.com/GEVOteach>

~ Thank you ~

Evolution Survey for Pre Service Teachers

Overview

This survey is part of the GEVOteach Project which is investigating how best to teach evolution in primary and secondary schools. By completing this survey you will be helping research by the Evolution Education Trust and the University of Bath.

The survey should take 15-20 minutes to complete. Please answer all questions and complete this survey without the help of any resources. Your views are important, not getting the 'right' answers!

All responses will be kept strictly confidential.

By completing this survey you will have the chance to sign up to receive free GEVOteach teaching resources for evolution topics. You will also have the chance to win a £50 Amazon voucher.

If you (or anyone else) has any questions about this project, then please do contact us:

Dana Buchan (Primary Schools)

Rebecca Mead (Secondary Schools)

**Department of Biology and Biochemistry
University of Bath
BA2 7AY**

email: l.buchan@bath.ac.uk (Primary) r.mead@bath.ac.uk (Secondary)

tel: 01225 385902

website: <http://go.bath.ac.uk/GEVOteach>

twitter: <http://twitter.com/GEVOteach>

~ Thank you ~

Evolution Survey for Pre Service Teachers

Background Information

* 1. At which university do you currently study?

* 2. Which phase are you training to teach?

- ☐ Early years specialist or FS/KS1 Primary
- ☐ General Primary (5-11)
- ☐ Middle
- ☐ Secondary
- ☐ Other (please specify)

* 3. What subject(s) are you training to teach?

* 4. Do you remember learning about evolution at any of these stages? (Please select all that apply.)

- ☐ GCSE or equivalent
- ☐ A Level or equivalent
- ☐ Degree
- ☐ Do not remember learning about evolution
- ☐ Other (please specify)

* 5. What is your highest qualification in biology?

- ☐ GCSE or equivalent
- ☐ A Level or equivalent
- ☐ Degree
- ☐ Other (please specify)

* 6. Do you identify with any of the following religions?

- ☐ Christianity
- ☐ Judaism
- ☐ Islam
- ☐ Buddhism
- ☐ Hinduism
- ☐ No religion
- ☐ Prefer not to say
- ☐ Other (please specify)

* 7. What is your gender?

- ☐ Female
- ☐ Male
- ☐ Other
- ☐ Prefer not to say

Evolution Survey for Pre Service Teachers

Evolution Acceptance (adapted from Rutledge and Warden 1999)

* 8. Please indicate your opinion for each of the following statements.

| | Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
|---|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 1. Organisms existing today are the result of evolutionary processes that have occurred over millions of years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 2. The theory of evolution is incapable of being scientifically tested. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 3. Modern humans are the product of evolutionary processes that have occurred over millions of years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 4. The theory of evolution is based on speculation and not valid scientific observation and testing. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 5. Most scientists accept evolutionary theory to be a scientifically valid theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 6. The available data are ambiguous as to whether evolution actually occurs. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 7. The first humans lived at the same time as dinosaurs. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 8. The age of the earth is less than 20,000 years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 9. There is a significant body of data that supports evolutionary theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

| | Strongly Agree | Agree | Undecided | Disagree | Strongly Disagree |
|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 10. Organisms exist today in essentially the same form in which they always have. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 11. Evolution is not a scientifically valid theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 12. The age of the earth is at least 4 billion years. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 13. Current evolutionary theory is the result of sound scientific research and methodology. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 14. Evolutionary theory generates testable predictions with respect to the characteristics of life. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 15. The theory of evolution cannot be correct since it disagrees with religious accounts of creation. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 16. Humans exist today in essentially the same form in which they always have. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 17. Evolutionary theory is supported by factual historical and laboratory data. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 18. Much of the scientific community doubts if evolution occurs. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
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| 20. With few exceptions, organisms on earth came into existence at about the same time. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 21. Evolution is a scientifically valid theory. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

22. Dinosaurs and humans have never existed at the same time.

Strongly Agree

☐

Agree

☐

Undecided

☐

Disagree

☐

Strongly Disagree

☐

Evolution Survey for Pre Service Teachers

Evolution Knowledge - Canary Island Lizards (adapted from Anderson, Fisher and Norman 2002)

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc.

Three different species of lizards found on the islands are similar to one species found on the African continent (Thorpe & Brown, 1999).

Because of this scientists assume that the lizards travelled from Africa to the islands by floating on tree trunks washed out to sea.

* 9. Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?

- ☐ Finding food is not a problem since food is always in abundant supply.
- ☐ Since lizards eat a variety of foods, there is likely to be enough food for all the lizards at all times.
- ☐ Lizards can get by on very little food, so the food supply does not matter.
- ☐ It is likely that sometimes there is enough food, but at other times there is not enough food for all the lizards.

* 10. What do you think happens among lizards of a certain species when the food supply is limited?

- ☐ The lizards compete for food and share what they find.
- ☐ The lizards fight for the available food and the stronger lizards kill the weaker ones.
- ☐ Genetic changes that would allow the lizards to eat new food sources are likely to be induced.
- ☐ The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

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- ☐ All lizards in the population are identical to each other on the outside, but there are differences in the internal organs such as how they digest food.
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| Lizard D | 15 | 26 | 6 | Has largest territory |

- ☐ Lizard A
- ☐ Lizard B
- ☐ Lizard C
- ☐ Lizard D

* 14. According to the theory of natural selection, where did the variation in body size in the three species of lizards most likely come from?

- ☐ The lizards needed to change in order to survive, so beneficial new traits developed.
- ☐ The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
- ☐ Random genetic and sexual recombination both created new variations.
- ☐ The island environment caused the genetic changes in the lizards.

* 15. What would cause one species to change into three species over time?

- ☐ Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
- ☐ Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.
- ☐ There may be minor variations, but all lizards are essentially alike and all are members of a single species.
- ☐ In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

Evolution Survey for Pre Service Teachers

Evolution Knowledge - General Questions

* 16. Which of the following phrases best describes the process of evolution?

- ☐ The development of man from monkey-life ancestors.
- ☐ The change of simple to complex organisms.
- ☐ The development of characteristics in response to need.
- ☐ Genetic change in populations through time.

* 17. Which of the following is not a part of the theory of evolution by natural selection?

- ☐ Individuals of the same species show variation.
- ☐ Organisms tend to produce more offspring than survive to adulthood.
- ☐ Modifications an organism acquires during its lifetime can be passed to its offspring.
- ☐ Some characteristics can be inherited.

* 18. Which of the following statements is most acceptable from an evolutionary point of view?

- ☐ Apes and humans have evolved from a common ancestor.
- ☐ Humans have evolved from apes.
- ☐ Certain apes have gradually evolved into humans.
- ☐ Apes and humans are related.

* 19. Scientists surveyed the number of light and dark coloured moths in woods where trees had either light or dark (polluted) coloured trunks. They found more light coloured moths in woods with light trees and more dark coloured moths in woods with polluted trees. This data provides support for:

- ☐ Artificial selection.
- ☐ Extinction.
- ☐ Inheritance of acquired characteristics.
- ☐ Natural selection.

* 20. Natural selection is:

- ☐ The same thing as evolution.
- ☐ A possible but unproven mechanism of evolution.
- ☐ Only one of many possible mechanisms of evolution.
- ☐ The inheritance of acquired characteristics.

* 21. Scientists have found evidence to suggest that the first life appeared on earth approximately:

- ☐ 10 thousand years ago.
- ☐ 270 million years ago.
- ☐ 3 billion years ago.
- ☐ 6 billion years ago.

* 22. The wing of the bat and the fore-limb of the dog are said to be homologous structures. This indicates that:

- ☐ They have the same function.
- ☐ Bats evolved from a lineage of dogs.
- ☐ They are structures which are similar due to common ancestry.
- ☐ The limb bones of each are anatomically identical.
- ☐ They have a different ancestry but a common function.

* 23. Marine mammals have many structural characteristics in common with fishes. The explanation that evolutionary theory would give for this similarity is:

- ☐ Fish and mammals are closely related.
- ☐ Fish evolved structures similar to those already existing in mammals.
- ☐ Marine mammals evolved directly from the fishes.
- ☐ Marine mammals never developed use of limbs.
- ☐ Marine mammals adapted to an environment similar to that of the fishes.

* 24. Please confirm which school age you mainly teach:

- ☐ Primary
- ☐ Secondary

Evolution Survey for Pre Service Teachers

Genetics Knowledge

* 25. Place the following items in order of size, starting with the largest first (1) and the smallest last (5):

| | | |
|----------------------|--------------------------|------------|
| <input type="text"/> | <input type="checkbox"/> | Cell |
| <input type="text"/> | <input type="checkbox"/> | Chromosome |
| <input type="text"/> | <input type="checkbox"/> | Gene |
| <input type="text"/> | <input type="checkbox"/> | Organism |
| <input type="text"/> | <input type="checkbox"/> | Nucleus |

* 26. Complete the following table by placing a tick in each of the boxes where you consider "yes" to be the answer to the question:

| | Are they living organisms? | Are they animals? | Are they made up of cells? | Do they contain genetic information? |
|----------|-------------------------------|--------------------------|-------------------------------|---|
| Humans | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Giraffes | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Moths | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Oak Tree | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Bacteria | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Virus | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

* 27. Complete the following table by choosing the words which best fits the description. Each word may be used once, more than once, or not at all.

| | environmental | genetic | sexual | DNA | alleles | asexual | clone | variation | gamete | mutation |
|---|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Different forms of genes. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| A change to the DNA sequence. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| An individual that is genetically identical to its parents. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| A sex cell. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Reproduction which needs only one parent. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Variation which is due to inheritance. | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

* 28. Muscle cells, nerve cells, and skin cells have different functions because each type of cell:

- ☐ Contains different kinds of genes.
- ☐ Is located in different areas of the body.
- ☐ Activates different genes.
- ☐ Contains different numbers of chromosomes.

* 29. How do plants reproduce?

- ☐ Sexual reproduction.
- ☐ Asexual reproduction.
- ☐ Both sexual and asexual reproduction.
- ☐ Plants do not reproduce.

* 30. Transferring genes from one organism to another is called:

- ☐ Cloning.
- ☐ Evolution.
- ☐ Genetic engineering.
- ☐ Tissue culture.

Evolution Survey for Pre Service Teachers

Confidence and Comments

* 31. For the following items, please indicate your level of confidence with the given statements:

Not at all confident Not confident Fairly confident Confident Really confident

How confident are you about teaching students how to "Recognise that living things have changed over time and that fossils provide information about living things that inhabited the Earth millions of years ago."?

☐☐☐☐☐

How confident are you about teaching students how to "Recognise that living things produce offspring of the same kind, but normally offspring vary and are not identical to their parents."?

☐☐☐☐☐

How confident are you about teaching students how to "Identify how animals and plants are adapted to suit their environment in different ways and that adaptation may lead to evolution."?

☐☐☐☐☐

Evolution Survey for Pre Service Teachers

Confidence and Comments

* 32. For the following items, please indicate your level of confidence with the given statements:

| | Not at all confident | Not confident | Fairly confident | Confident | Really confident |
|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| How confident are you about teaching science in general? | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| How confident are you about teaching evolution? | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

* 33. Do you have any major concerns about teaching evolution?

* 34. Do you think there are any areas of evolution that you need further support with?

* 35. How could the GEVOteach Project help to support you? (Please select all that apply.)

- ☐ Discussion with other teachers
- ☐ Inset training
- ☐ Resources
- ☐ Web based information
- ☐ I don't feel as though I need any support
- ☐ Other (please specify)

* 36. Do you have any other comments you would like to make about teaching evolution?

Evolution Survey for Pre Service Teachers

Contact Details for Free Resources

37. Please provide us with your contact details if you would like to receive free resources from GEVOteach*.

| | |
|----------------------|----------------------|
| Name | <input type="text"/> |
| Address 1 | <input type="text"/> |
| Address 2 | <input type="text"/> |
| City/Town | <input type="text"/> |
| County | <input type="text"/> |
| Postal Code | <input type="text"/> |
| Country | <input type="text"/> |
| Email Address | <input type="text"/> |
| Phone Number | <input type="text"/> |

38. Please select which free resources you would like to receive from GEVOteach**

- ☐ Primary
- ☐ Secondary
- ☐ Both

* Resources will be sent via memory stick to the first 50 trainee teachers to complete this survey before 30/09/15. Resources will be sent via disc or internet link to all other trainee teachers who complete the survey and indicate that they would like to receive resources. Resources will be available from August 2015 onwards.

**Primary resources contain resources for teaching evolution; Secondary resources contain resources for teaching genetics and evolution.

39. Please provide us with your contact details if you would like to be entered into a draw to win an Amazon voucher worth £50***.

| | |
|----------------------|----------------------|
| Name | <input type="text"/> |
| Email Address | <input type="text"/> |
| Phone Number | <input type="text"/> |

*** Survey must be completed on or before 30/09/15 to be entered into the draw.

40. Please provide us with your contact details if you would like to receive more information about GEVOteach research.

Name

Email Address

Phone Number

Please complete this survey by clicking on the **Done** button (below).

All responses will be kept strictly confidential.

If you (or anyone else) has any questions about this project, then please do contact us:

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twitter: <http://twitter.com/GEVOteach>

~ Thank you ~